

Science and technology should play a strategic role in Brazil, given the need to improve productivity in the economy, to deal with problems of poverty, education, health and environment degradation, and to participate more fully in an integrated world economy and society.



SCIENCE AND TECHNOLOGY IN BRAZIL:

A NEW POLICY FOR A GLOBAL WORLD

Simon Schwartzman (coord.)
Carlos Osmar Bertero
Eduardo Augusto Guimarães
Eduardo Krieger
Eugene B. Skolnikoff
Fernando Galembeck
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Science and Technology in Brazil: A New Policy for a Global World

Volume 1

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EDITORA

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Summary

Foreword I

Science and technology in Brazil: a new policy for a global world,
by Simon Schwartzman, Eduardo Krieger, Fernando Galembeck, Eduardo Augusto Guimarães and Carlos Osmar Bertero I

Comments on "Science and Technology in Brazil",
by Michael Gibbons 57

Science & technology in the new world order,
by Georges Ferné 72

United States science and technology policy: the effects of a changing
international environment,
by Eugene B. Skolnikoff 105

United States science and technology policy: issues for the nineties,
by Lewis M. Branscomb 140

Performance, specialization and international integration of science in Brazil:
changes and comparisons with other Latin American countries and Israel,
by Thomas Schott 227

Foreword

The papers included in this volume were prepared for a policy study on science and technology in Brazil carried on between 1992 and 1993 by the Escola de Administração de Empresas de São Paulo, Fundação Getúlio Vargas. The study was done at the request of the Brazilian Ministry of Science and Technology, within the Program for Scientific and Technological Development (Programa de Apoio ao Desenvolvimento Científico e Tecnológico, PADCT II). A second volume includes papers written in Portuguese, dealing with the institutional aspects of science and technology, and its economic and social implications. The third volume, also in Portuguese, brings together papers about specific sectors of scientific and technological activities in Brazil. The coordination team included Simon Schwartzman (Fundação Getúlio Vargas and University of São Paulo, general coordination), Eduardo Moacyr Krieger (Instituto do Coração and Brazilian Academy of Sciences, biological sciences), Fernando Galembeck (University of Campinas, physical sciences and engineering), Eduardo Augusto Guimarães (Federal University of Rio de Janeiro, economic dimensions) and Carlos Bertero (Fundação Getúlio Vargas, administrative and institutional aspects), with management support from José Roberto Ferro (Federal University of São Carlos and Fundação Getúlio Vargas).

After a brief period of rapid expansion in the 1970's, the Brazilian scientific and technological sector entered a time of instability and uncertainties in the 1980's characterized by reduced and uncertain resources, successive institutional reorganizations, and a general feeling of uneasiness about the role science and technology were supposed to play in the country. In the 1980's, the two programs for scientific and technological development (PADCT I and PADCT II) signed between the Brazilian government and the World Bank provided some degree of resource stability to a few selected sectors, but did not replace the need for a broader policy and a clearer perspective. This need became apparent in the negotiations between the Brazilian government and international agencies, such as the World Bank and the Interamerican Development Bank, for additional loans to the science and technology sector. In consequence, three studies were commissioned by the Brazilian government to evaluate and make suggestions for the future. One, carried on within the Ministry of Science and Technology itself, with support from the United Nations Development Program, looked more specifically into the institutional aspects of the S&T sector. Another, led by Luciano Coutinho at the University of Campinas, also within the PADCT II program, concentrated on technological innovation in the Brazilian productive sector. The third was our study, aimed at an assessment of Brazil's scientific and technological capabilities in the current national and international context, and the formulation of a new perspective for the whole sector.

The conclusions, presented in the first chapter of this volume, do not represent the official view of the Brazilian government. They are the sole responsibility of the coordinating team and individual paper authors, and are presented to the gov-

ernment and the public as suggestions and proposals for discussion. The study was carried on without government interference and with complete freedom for the participants to express their views and perspectives, and the same freedom was granted to the authors of each commissioned paper. In March, 1994, the Fundação Getulio Vargas organized a seminar where participants of the three studies presented their main conclusions to the Ministry of Science and Technology, government officials and the public, and since then the wealth of materials produced are being disseminated and brought under scrutiny.

The main assumption of our study is that science and technology should play a strategic role in Brazil, given the need to improve productivity in the economy, to deal with problems of poverty, education, health and environment degradation, and to participate more fully in an integrated world economy and society. The incorporation of technical knowledge in the productive process is necessary not only to guarantee the competitiveness of Brazil's products in the international market, but also to assure that the benefits of this activity are absorbed by the country's broader population. Poverty, education, health and environment are problems of exceeding complexity, which cannot be dealt with without the benefit of specific technological innovations, and the proper understanding of their broader causes, implications and consequences. But science and technology are not just embodied in pieces of equipment, registered patents and technical literature in bookshelves and computer disks. They exist, above all, in the culture and daily practice of human beings, as part of their education and life experiences. The more this culture and practical experiences spread in society, the more society can benefit from them. This is why no science and technology policy can be successful if it is not part of a much broader policy to expand, improve and consolidate basic education, and to increase the competence of the productive system as a whole. This concern with the internal benefits of science and technology is not in contradiction, but in fact requires, an active participation in the international markets and networks for technological products and scientific knowledge, through the elimination of barriers to technological transfers and investment in the improvement of innovative capabilities and scientific competence of individuals, firms and educational and research institutions.

The Brazilian scientific and technological system which took shape in the 1970's worked from a completely different set of assumptions. Regarding the role of technology, the assumption was that it was necessary to concentrate efforts and resources in a few large strategic projects, to free the country from the *technological encirclement* of foreign governments and multinational firms, and to generate poles from which scientific and technological competence could *trickle down* to the economy and society as a whole. The current understanding is that, although proprietary knowledge is in the rise worldwide, and controls of the transfer of military sensitive technologies persist, the key element allowing access to the benefits of scientific and technological developments is the general competence of the population and of the economic system as a whole. Knowledge usually does not spread enough vertically, from big projects to small firms, or from basic to applied science; but goes very often in the opposite direction, from basic

knowledge and innovative competence to more ambitious projects and tasks. A corollary is that an environment which is open to the circulation and transfer of technologies of all kinds is more advantageous to the country than a closed or overprotected environment.

Regarding science, the usual understanding was that Brazil should develop scientific capability in all fields, starting if necessary with small groups, protected from international scientific competition. Eventually, these groups would reach international standards, and spin off to the broader economy and society. It was a replication of the *import substitution policies* from the industrial to the scientific and technological sectors. The current understanding is that there is no room for second rate, protected basic science in the current world scientific environment. Even small scientific communities should be up to international standards, and participate fully in international scientific networks.

The consequence of the old assumptions was a combination of a few ambitious high technology projects, such as the nuclear and the space programs, and a fairly large network of graduate programs and research institutes, not necessarily of the best quality. The preferred scenario today is the opposite: a small but highly qualified research establishment, and widespread diffusion of basic technological competence and professional education.

It was also assumed in the past that science, and more specifically technology, should be subject to detailed and long-term planning, leading, to the development of complex administrative structures. The current view is that these planning bureaucracies should be replaced by light, rapid and efficient decision mechanisms, with strong emphasis on decentralization and local autonomy.

Thirdly, it was assumed in the past that public resources for science and technology were abundant and would grow continuously, allowing for an expectation of continuous expansion. Today, it is clear that we have entered an era of limited resources, specially in the public sector, requiring harder choices in resource allocation, and stronger needs of association with the private sector.

Finally, while in the past it was assumed that investments in science and technology were always for the good, there is a growing awareness today about the need to evaluate the costs, benefits and alternative use of resources, specially regarding large scale projects.

These assumptions of the past have still not been fully revised, and shape many current proposals and ideas. The full implications of this conceptual shift are spelled out in the papers now being published, and are gradually being absorbed by Brazilian society. As they do, they will add to the country's efforts to become a more competent, economically viable and just society.

Rio de Janeiro, March 1995

Simon Schwartzman

Science and technology in Brazil: a new policy for a global world*

Simon Schwartzman

Eduardo Krieger

Fernando Galembeck

Eduardo Augusto Guimarães

Carlos Osmar Bertero

Summary

Brazil developed, in the last quarter of a century, a very significant effort to build its scientific and technological capabilities, but in the last decade this sector has suffered intensely from lack of resources, institutional instability and lack of clarity about its role in the economy, society and education. Brazil's science and technology sector is in need of urgent action. Recent transformations in the world's economy have made a country's scientific, technological and educational competence more important than ever to increase production, raise the standards of living of its population, and deal with its social, urban and environmental problems. Policies for science and technology can only be fruitful in association with coherent policies and actions for economic adjustment, education and industrial development. Policies from the central government can only be effective if they involve the active participation of state and local governments and of business, workers, educators and the scientific and technological community. The proposals put forward in this document should not be seen in isolation, but as a contribution to a much broader effort.

This policy paper was prepared by the Getulio Vargas Foundation at the request of Brazil's Ministry of Science and Technology and the World Bank, as established by the II Program for Scientific and Technological Development (the PADCT II agreement). The work was carried on with the cooperation of an independent group of scientists, economists and specialists of science policy in Brazil and abroad, which produced about 40 papers dealing with the international context, Brazil's scientific and technological capabilities, the links between science, technology and the economy, and Brazil's institutions for science and technology

* This is the summary document of the science and technology policy study carried on by the São Paulo School of Business Administration, Getulio Vargas Foundation, for the Brazilian Ministry of Science and Technology, within the Program for Scientific and Technological Development (the PADCT II agreement between Brazil and the World Bank). The ideas expressed in this text are the sole responsibility of its authors.

support. This final document is the responsibility of the projects' coordinating team, and does not express necessarily the opinions of the Brazilian government, the World Bank, the Fundação Getulio Vargas, nor of the individuals who contributed with specific studies.

The main thrust of this policy paper is that there is a definite need to move from the previous mode of scientific and technological development into a new one, more adequate to the current and future realities. This policy paper presents a summary of what Brazil's science policy was in the recent past, the current situation, an overview of the recent transformations of science and technology in the international context, and puts forward some proposals for new directions. To implement these recommendations, the Brazilian government, with the support of the World Bank and other sources, should establish a high-level task force to evaluate this and other policy studies now being concluded, and propose specific policy measures to be carried on by the Ministry of Science and Technology and other agencies, and to be presented to Parliament to be enacted in law when necessary. The main recommendations are summarized below.

Recommendations

Science and technology are more important than ever for Brazil, if the country is to raise the standards of living of its population, consolidate a modern economy, and participate as a significant partner in an increasingly integrated and global world. The economy must modernize, and adjust to an internationally competitive environment. Education should be expanded and improved at all levels. As the economy grows and new technologies are introduced, new challenges will emerge in the production and use of energy, environment control, public health, the management of large urban conglomerates, and changes in the composition of the labor force. Strong indigenous competence will be necessary to participate as an equal in international negotiations and in the setting of international standards that may have important economic and social consequences for Brazil.

The new policy should steer away from the extremes of *laissez-faire* and centralized planning. A traditional, *laissez-faire* approach to scientific and technological development will not produce the necessary competence on the scale and quality needed for these tasks. Large-scale, sophisticated and highly concentrated technological projects are not likely to spin off into education and industrial development as a whole. Attempts to bring the whole field of science and technology under the aegis of centralized planning and coordination run the risk of stimulating large and inefficient bureaucracies, and to stifle initiative and creativity of research.

The new policy should implement tasks that are apparently in contradiction: to stimulate the freedom, initiative and creativity of the researcher, while establishing strong links between his work and the requirements of the economy, the educational system and of society as a whole; and to make Brazilian science and

technology truly international, while strengthening the country's educational and S&T capabilities.

To fulfill these tasks, the following recommendations are made:

Technology and applied science

(a) to redirect the country's technology policies, in line with new economic realities. On the short run, policies should be geared to the reorganization and technological modernization of the industrial sector. Permanent policies should exist to induce the more dynamic sectors of the productive system to enter a continuous process of innovation and incorporation of new technologies, to follow the rhythm of technical progress in the world economy. Both approaches require, as the main priority, the incorporation of existing technology to the productive process;

(b) research groups in universities and government institutes should be strongly stimulated to link to the productive system and to engage in applied work, while maintaining a high level of academic and basic research activities. Resources for applied work should not come from the budget for basic activities, but from specific sources in governmental agencies, special programs, private firms, and independent foundations. Applied projects should be evaluated in terms of their academic quality, but also of their economic viability and social and economic significance;

(c) the current situation, in which 80 per cent or more of the current expenditures are public, should be changed. This should not be done by reducing further the government's expenditures in R&D, but by stimulating the private sector to invest more in this sector;

(d) government agencies dealing with matters requiring research work, such as health, education, environment, energy, communications and transportation, should have resources to contract research with universities and research institutions on matters of their interest. This practice should prevail upon the tendency of these agencies to create their own research outfits, and their projects should be subject to joint evaluations by peer review and policy oriented authorities. Research institutes and centers in public agencies and state companies should be placed under peer oversight, and required to compete for outside research support;

(e) the current military projects should come under technical, academic and strategic evaluation with the participation of selected, high quality scientific advisers.

ers, and be either streamlined, discontinued, reduced, or converted to civilian projects;

(f) research programs in applied fields, like electronics, new materials, biochemistry and others, should only be established in association with identified partners in industry, which should be involved from the beginning in setting objectives and in sharing costs; they should be subject to independent evaluations of economic, managerial and scientific feasibility, and monitored on these terms.

Basic science and education

Support for basic science should be maintained and expanded, with special attention to its quality, according to accepted international standards. Basic or academic science, broadly understood as research work that does not respond to short-term practical demands, remains essential for Brazil. The information it generates is free, and is the main source for the acquisition and spreading of the basis of tacit knowledge that permeates the whole field of science, technology and education. For a leading country, heavy investments in basic science can be thought of as problematical, since their results can be appropriated by other countries and regions for very little cost. For the same reason, investments in basic science in small scientific communities can be extremely productive, since they allow tapping the international pool of knowledge, competence and information.

The existing pool of scientific competence has to be protected. Many of the best R&D institutions and groups are being dismantled by absolute lack of resources, and emergency measures are needed to deter this process. The government should guarantee a stable and predictable flux of resources to its main S&T agencies for their daily routines and "over the counter", peer reviewed research supporting activities. The most qualified research institutions and groups should be preserved in their ability to keep their best researchers and their work and educate new scientists. The main mechanism for this should be the implementation of the proposed system of "associated laboratories", which should provide stable resources to about 200 research groups and institutions, based on clear procedures of evaluation and peer review. The estimated cost for maintaining this program is approximately US\$200 million a year; a similar amount will be needed to provide these laboratories with basic equipment and infrastructure.

Research institutions, particularly in universities, should be required to play a very active role in the enhancement of undergraduate and technical education, not only through teaching, but also through direct involvement in the production of good quality textbooks, the development of curricula and new teaching methods and programs of continuous education. Adequate mechanisms should be devised to make these activities more rewarding and prestigious than they have been so far.

International cooperation

Globalization requires a profound rethinking of the old dilemma between scientific self-sufficiency and internationalization. They should not be perceived as contradictory, but as complementary. Brazil has much to gain as it increases its ability to participate fully as a competent and respected partner in the international scientific and technological community. To meet this objective, the following policies should be implemented:

(a) fellowship programs of Capes and CNPq for studies abroad should be revised, maintained, and eventually expanded. Fellowships should be awarded only to first-rate students, going to first-rate institutions, with a clear perspective of returning to productive work in Brazil. Fellowships for doctoral degrees should be combined with "sandwich" fellowships for doctoral students in Brazilian institutions for reduced periods abroad, and with short-term support for training periods in laboratories and companies. The existence of good quality doctoral programs in a given field does not preclude the need to keep a permanent flux of students to the best foreign universities;

(b) provisions should exist for post-doctoral programs both abroad and in Brazil, and to bring top-quality scholars from other countries for extended periods, or even permanent appointments, in Brazilian university and research institutions;

(c) the channels for international cooperation between Brazil, international agencies and institutions, and the international scientific community, should be kept open and expanded. The World Bank, the International Development Bank and the United Nations Development Program have played important roles in providing resources for capital investment, research support and institutional development for Brazilian institutions. This presence should be maintained not only because of the resources involved, but because of what they bring in terms of international perspectives and competence. In the future, such agencies could be very helpful in a process of institutional reform. As a rule, cooperation among scientists, research institutions and private foundations in different countries is established directly, and needs the support, but not the interference, of governmental agencies;

(d) the issues of protectionism *versus* market competitiveness in scientific and technological development should be dealt in pragmatic, rather than in ideological terms. The country should not renounce to its instruments of technological and industrial policy, including tax incentives, tariff protection, patent legislation, government procurement and long-term investments in technological projects, in association with the private sector. Adequate legislation for patents and intellec-

tual property should be established with the understanding that they are necessary for the normalization of Brazil's relations with the industrialized countries.

Information and knowledge dissemination

New and systematic means to incorporate technology into the industrial process should be developed, with strong emphasis on the development and dissemination of norms and standards, information, and procedures for technological transfer and quality improvement. A well organized and properly funded knowledge infrastructure is necessary to assure the easy access of scientists to libraries and data collections in the country and abroad, making use of the latest technologies of electronic communication and networking. It is necessary to make these links effective and transparent to the individual researcher, and to establish mechanisms to bring texts and data to the scientist's working place. The role of CNPq's Brazilian Institute for Scientific and Technological Information (Ibict) should be reexamined in the light of the new technologies and competencies developed elsewhere.

Institutional reform

The Ministry of Science and Technology should restrict its role to matters of policy, financing, assessment and evaluation, without carrying R&D activities under its direct administration. Although a cabinet-level position for science and technology is clearly necessary, the very existence of a ministry of science and technology, with all its overhead costs and exposure to political patronage, should be reexamined.

The existing system of federal institutions for scientific and technological support should be evaluated in terms of its ability to perform the functions needed by the sector: support for basic research, support for applied projects, large and small research grants, fellowship and training programs, scientific information, norms and standards, and others. Brazil needs a federal agency to provide long term, sizeable grants for institutions and cooperative projects. This was the role played in the past by the National Fund for Scientific and Technological Development (FNDCT), administered by Finep. Whether these resources should be managed by Finep, CNPq or by a new institution should be examined as part of a broad review of the roles, jurisdiction and competencies of the existing agencies.

Financing agencies should be organized as independent, state owned corporations, and free of formalistic and bureaucratic constraints. They should be placed under strict limitations regarding the percentage of resources they can spend on administration, and should be supervised by high-level councils with the participation of scientists, educators, entrepreneurs and government officers.

They should rely on external advice for their decisions, and their bureaucracy should be limited to the minimum.

Research institutions and public universities should not be run as sections of the civil service. They need to be free to set priorities, seek resources from different public and private agencies, and establish their own personnel policies.

No research institution receiving public support, and no government program providing grants, fellowships, institutional support or other resources to the S&T sector, should be exempt from clear and well-defined procedures of peer evaluation, combined, when necessary, with other types of economic and strategic assessments. Peer review procedures should be strengthened by the federal and state governments, made free from pressures of regional, professional and institutional interest groups, and acquire a strong international dimension. For instance, research proposals could be easily distributed to international referees through electronic mail.

Goal-oriented projects

The broad changes suggested in this document do not preclude the adoption of well-identified projects linking science, technology and the productive sector, to deal with specific questions and problems and to strengthen the country's capabilities in selected areas. It is necessary to develop a list of main areas of established competence and social, economic and environmental relevance, which should be the focus of future investments; to identify areas that should be phased out, or reduced; and special weaknesses and competencies in need of strengthening and support.

1. Science and technology in Brazil

Brazil developed in the last 25 years the largest system of S&T in Latin America, one of the most significant among semi-industrialized countries. There are about 15,000 active scientists and researchers in the country, and about 1,000 graduate programs in most fields of knowledge.¹ Fellowships keep several thousand students in the best universities in the United States and Europe at any time. The number of research papers in international publications is the highest in the region. Research takes place mainly in the major

¹ This figure depends on what a "researcher" is. The Brazilian National Research Council (CNPq) listed 52,863 researchers in 1985, for about 3.5 million persons with higher education degrees. However, only 21.7 per cent of those, or 11,000, had doctoral degrees. The number of university professors with doctoral degrees in 1991 was about 17,000, or 12 per cent of the total. This figure is also consistent with the number of research proposals presented to Fapesp and CNPq each year (Brisolla; Martins & Queiroz, 1987; Schwartzman & Balbachovsky, 1992). As for the graduate programs, the figure depends on whether one counts degrees offered or course programs proper.

universities, such as the University of São Paulo, the Federal University of Rio de Janeiro, the University of Campinas and the São Paulo School of Medicine; in research institutes linked to the Ministry of Science and Technology, such as the National Institute for Space Research, the National Institute for Research on the Amazon and the National Institute of Technology; in research institutes belonging to the National Research Council (the Brazilian Center for Physics Research, the Center for Mineral Technology, the Institute of Applied and Pure Mathematics, the National Observatory, the National Laboratory for Computer Sciences, the National Laboratory of Astrophysics, the Emílio Goeldi Museum of Natural History, and the National Laboratory of Synchrotron Light); in the Brazilian Corporation for Agricultural Research (Embrapa), linked to the Ministry of Agriculture; in the Oswaldo Cruz Institute, linked to the Ministry of Health; in research centers kept by the largest state-owned corporations, such as Petrobrás (oil), Telebrás (telecommunications), Eletrobrás (electricity) and Embraer (airplane construction); in research units linked to the armed forces, such as the Air Force Technological Center (CTA); in institutes belonging to state governments, specially in São Paulo, like the Butantã Institute (vaccines), the Biological Institute and the Institute for Technological Research (IPT); and in a few leading private corporations, such as Aracruz Celulose (paper), Itautec (computers), Aço Villares, Metal Leve (mechanical components), Elebra (computers), and others.

Most research activities in Brazil take place in universities. Brazil has about 1.5 million students enrolled in undergraduate programs, 30,000 in masters and 10,000 in doctoral programs. About one third of the undergraduate, and most of the graduate students are in public universities, which are free of charges. The remaining 1 million attends private institutions, which, with very few exceptions, do not have graduate education and research. The Federal government spent about US\$3.4 billion on higher education in 1990, and the state of São Paulo an additional US\$871 million for its three universities (Goldemberg, 1993b; Durham, 1993; Campanário & Serra).² The gross per capita costs for students in public universities are between US\$5,000 to US\$8,000 a year, with most of the money going for salaries and the maintenance of hospitals.³ For research, university professors have to apply to Federal or State agencies, national and international private foundations, or to engage in research contracts with governments, public corporations and, to a lesser degree, private institutions.

² These figures are only rough estimates, because of high inflation and unstable exchange rates.

³ For different perspectives on student costs, see Paul & Wolyne (1990), and Gaetani & Schwartzman (1991). The estimation is that hospitals absorb about 10 per cent of university's budgets (they have also other sources of income).

Table 1
Brazil, expenditures in science and technology and gross domestic product, 1980-90, in US\$ millions of 1991¹

Year	Federal budget ²	State budgets ²	Government expenditures (1 + 2)	Expenditures of the productive sector	National expenditures (3 + 4)	National expenditures as % of GDP	Gross domestic product (GDP) ³
1980	824.5	496.8	1,321.3	330.3	1,651.6	0.43	386,863.3
1981	1,519.6	672.4	2,192.0	548.0	2,740.0	0.74	370,279.2
1982	1,863.3	654.6	2,517.9	629.5	3,147.4	0.85	372,122.9
1983	1,475.4	462.6	1,938.0	484.5	2,422.5	0.67	359,727.6
1984	1,426.9	500.7	1,927.6	481.9	2,409.5	0.64	378,422.2
1985	1,953.9	501.9	2,455.8	613.9	3,069.7	0.75	408,151.6
1986	2,288.6	651.3	2,939.9	735.0	3,674.9	0.84	439,451.0
1987	2,556.1	466.9	3,023.0	755.7	3,778.7	0.83	455,424.2
1988	2,506.4	396.7	2,903.1	725.8	3,628.9	0.80	454,918.0
1989	2,147.1	512.5	2,659.6	664.9	3,324.5	0.71	469,663.5
1990	1,679.0	672.2	2,351.2	587.8	2,938.9	0.72	406,906.4

Source: Brisolla. Data from MCT-CNPq/DAD/SUP/COOE.

¹ Deflated according to general price index of the Fundação Getúlio Vargas (IGP-DI/FGV) and converted to US dollars according to the average rate for 1991.

² Actual expenditures.

³ Corrected for inflation and converted to US dollars according to the average rate for 1991.

The development of these activities was accompanied by the creation of a complex system of institutions, which are presently led by the Ministry of Science and Technology (MCT). MCT is formally responsible for coordinating S&T policy in all areas, directly or through agencies such as the National Council for Scientific and Technological Development (CNPq) and the Financing Agency for Studies and Projects (Finep). Besides, both MCT and CNPq have research institutions under their jurisdiction. The Ministry of Education has a specialized agency to support graduate education in Brazil and abroad, the Coordination for High Level Manpower Education (Capes). Most states have secretaries for Science and Technology, and legislation providing funds for research, to be administered in most cases by specialized agencies. The oldest and largest of these, the São Paulo's Fundação de Amparo à Pesquisa (Foundation for Research Support — Fapesp), receives about 1 per cent of the state revenues, which in 1992

amounted to about US\$70 million, and profits from its capital investments. There are 10 similar agencies in other states. They are supposed to receive between US\$180 and 320 million a year from similar arrangements (including Fapesp), although in practice they receive much less.⁴ There is a sizeable network of scientific and professional societies publishing around 400 journals, organizing conferences and lobbying for their special interests and perspectives. An association of industrial research centers in private companies was created recently. Financial data are not very reliable, since there is no clear definition of what the figures on public expenditures in science and technology really mean. They may refer to administrative and financial expenditures, rather than to science and technology as such; they may be distorted by inflation variations; and information about the private sector is scarce. The estimate is that, between 1981 and 1989, Brazil spent between about US\$2-3 billion a year in science and technology activities, amounting to about 0.6 to 0.8 per cent of the GDP. Of this, only about 6 per cent came from the private sector, and another 10 per cent from state-owned corporations (Brisolla; Coutinho & Suzigan, forthcoming; Wolff, 1991). These resources have been subject to high levels of instability in the last several years, in a context of near hyperinflation and economic stagnation.

Impressive as some of these achievements may be, they still leave Brazil as a minor player in the world's scientific community (box 1). Articles by Brazilian authors published in the international literature are less than 1 per cent of the world total. In 1992 Brazil ranked twentieth among nations in scientific production in absolute terms, trailing China, Belgium, Israel and Denmark, and ahead of Poland, Finland, Austria, Norway, Taiwan and Korea (Castro, 1986; Schott). Links between scientific research and the productive sector are weak, and its impact on the quality of undergraduate and technical education is limited, a few significant exceptions notwithstanding.

2. Background

The beginning: S&T development in a period of economic expansion

Some of Brazil's scientific institutions date from the late 19th century, and the National Research Council from the early 1950's. The larger part of the current S&T capability, however, was built during the 1968-80 years, in a period of military rule (Schwartzman, 1991). Three factors contributed to this rapid expansion. The concern of some military and civilian authorities with the need to build

⁴ The estimate, made by the Brazilian Society for the Advancement of Science (SBPC), is that in 1991 the states were supposed to provide US\$317 million for research activities, but granted only 84 million. Figures for 1992 were 182 and 82 million. Of the total spent, about 70 per cent came from Fapesp (Brisolla).

up the country's S&T competence, as part of a broader project of national growth and self-sufficiency; the support this policy received from the scientific community, in spite of earlier (and often continuing) conflicts between scientists and academics and the government; and the economic expansion of the period, in which Brazil's economy grew at an annual rate of 7 to 10 per cent. Another important element was the improvement of the government's ability to carry out policies in those years, through the establishment of small, independent agencies outside the federal bureaucracy, and an expanding fiscal basis.

Box 1

Brazilian science in context

Brazil is a scientifically small country, performing much less than 1 per cent of the scientific research in the world, and this attracts much less than 1 per cent of the citations in subsequent literature. No Brazilian scientist was among the nearly 3,000 mentioned as principal contributors or significant influentials in a survey of scientists elsewhere. Brazilian research amounted to a little less than half of the research performed in the rest of Latin America and about a third of that performed in Israel, where scientific performance was high as indicated by the rather frequent mentioning of Israelis as great contributors and influentials. In economy and population, Brazil is roughly half the size of the rest of Latin America, as in science. But Brazil is a whole order of magnitude larger than Israel in terms of the economy and even more in terms of population and yet far less research is performed in Brazil than in Israel. This shows that scientific performance in a country is not a reflection of the size of the country in terms of population or economy (there is only a very weak correlation with population and a weak correlation with the economy). These differences in scientific performance seem shaped by differences in institutionalization of science.

Thomas Schott.

The policies of the last 25 years should be seen in terms of the changes in Brazilian society and economy in the previous decades. Between 1950 and 1980 Brazil turned from an agrarian into a highly urbanized society, but with high levels of social and economic inequality between regions and social groups. Employment in the primary sector went from 59.9 per cent of the active population to 29.9 per cent in those 30 years, while industrial employment went from 14.2 per cent to 24.4 per cent; the service sector, meanwhile, went from 25.9 per cent to 45.7 per cent (Faria, 1986). The industrial sector developed under the protection of tariff and non-tariff barriers that shielded national, multinational and state-owned companies in the Brazilian territory from international competition.

By 1970, the Brazilian industry supplied most of the demand for manufactured goods in the internal market, depending only on the import of sophisticated machine tools, chemicals, oil and electronics. A strategic program for development, set by the military government in 1968, sought to overcome these limitations. The country should build its own basic industry, develop its own sources of energy, and absorb the latest advances in science and technology. Starting with the second national development plan, public corporations were created or expanded, subsidies were provided for the private sector, and barriers were raised against foreign competition, to protect the country's infant industries. Science and technology were perceived as a central ingredient in this strategy, and received unprecedented support.

This ambitious project of scientific, technological and industrial self-sufficiency, however, did not receive more than scattered support in the productive sector, and remained for the most part restricted to special segments of the state bureaucracy and the academic community. For most firms, including the large, state-owned corporations, the origin of technologies used in their activities was less important than their cost and reliability. Restrictions to the entrance of foreign technology and capital — as it happened with the computer sector in the eighties — were perceived as a hindrance and a burden. This difficulty was accentuated because there was no understanding of the effective mechanisms and policies leading to technological innovation in the productive sector. The need to strengthen the country's basic technological infrastructure metrology, normalization, quality control and certification received only secondary attention, at least until the late seventies.

Main initiatives

The main initiatives of this period were the following:

- (a) the university reform of 1968, with the partial adoption of the American system of graduate education and the reorganization of the universities in terms of institutes, departments and the credit system;
- (b) the placement of science and technology under the responsibility of the economic policy authorities, which allowed for a much higher influx of resources to S&T than ever before;
- (c) the creation of a new federal agency for S&T under the Ministry of Planning, the Financing Agency for Studies and Projects, Finep, unencumbered by civil service routines and restrictions, and responsible for the administration of several hundred million dollars a year for science and technology support (Guimarães, R., 1993);

(d) the establishment of a few large-scale centers for R&D, like the Coordination for Graduate Programs in Engineering of the Federal University in Rio de Janeiro (Coppe) and the University of Campinas, geared toward technological research and graduate education in engineering and sciences;

(e) the beginning of several programs of military research, such as the space program and the "parallel" nuclear program;

(f) the agreement with Germany for cooperation in nuclear energy, which was to create an autonomous capability in the construction of nuclear reactors based on locally reprocessed fuel;

(g) the establishment of a policy of protected market for the computer industry, telecommunications and microelectronics, linked to an emerging national private sector;

(h) the formulation, by the Federal Government, of successive national plans for scientific and technological development;

(i) the establishment of centers for technological research under the main state-owned corporations, which sought to keep up with the technological frontier, develop standards and transfer technology to their main suppliers;

(j) the strengthening and expansion of Embrapa, the Brazilian Corporation of Agricultural Research;

(l) the consolidation of peer review procedures in some of the main public agencies for science, technology and graduate education: CNPq, Capes and the São Paulo Foundation for Research Support (Fapesp). The main federal agency for science and technology development in the seventies and eighties, however, Finep, never introduced systematic peer review procedures although it works routinely with external consultants. Larger decisions of resource allocation in CNPq also remained usually outside peer review.

Crisis in the eighties and nineties

It is possible to point to several weaknesses in an otherwise successful policy of scientific growth. Links between S&T and the productive sector remained weak, lacking demands for advanced technology, in an economic environment characterized by protectionism and reliance on cheap labor and natural resources. The only significant exceptions occurred in the modern, export oriented sector of agriculture, which benefitted from research on the introduction of new varieties, the control of plagues, and the biological fixation of nitrogen, with very signifi-

cant gains in productivity (Malavolta, 1986); in sectors associated with the large state corporations, such as telecommunications, energy, and the chemical industry; in the production of military equipment; and in the computer industry, with the attempt to link research with a protected industry of small computers for the internal market (Lucena; Tigre). In the universities, the new research and graduate programs remained often isolated from undergraduate education and teacher training. The quality of the scientific institutions created and expanded in the seventies was often not very high, and peer review procedures for quality control not always prevailed.

After 1980, the science and technology sector entered a period of great instability and uncertainty, characterized by institutional turmoil, bureaucratization, and budgetary uncertainty. The evolution of national expenditures for science and technology in the eighties, as illustrated on table 1, followed two parabolas. It grew in the first years of the decade, fell in 1983 and 1984, increased again with the short-lived economic expansion of the Cruzado Plan in 1985 and 1986, and fell rapidly when inflation picked up again in 1988, reaching its lowest levels in 1991 and 1992 (Brisolla). In 1985, the National Fund for Scientific and Technological Development administrated by Finep was just one fourth of its 1979 value. This instability and uncertainty were related to economic stagnation, but also to an expanding arena of conflicting interests striving for public funds, and to an increase in political patronage (Botelho, 1990 and 1992; box 2). The S&T sector became one among many interest groups pressing for more resources, sometimes with partial success, but losing ground on the long run. The same pattern took place in most public universities, particularly in the federal system. The growing unionization of academic and administrative personnel allowed for significant gains in salaries, employment benefits, and participation in the universities' management, but stifled the institutions' ability to improve quality and make better use of their resources.

The World Bank supported Program for Scientific and Technological Development (PADCT I, 1985, followed by PADCT II in 1990) was conceived in the early eighties, when the full dimension of the crisis was still to unfold. The program was supposed to improve the decision making capabilities of government and to strengthen R&D in biotechnology, chemistry and chemical engineering, earth sciences and mineral technology, instrumentation, physical environment and science education. In practice, instead of building upon a basis of existing resources, PADCT became often the only source of public support for the fields included in its priorities. Instead of improving the country's management and decision-making capabilities, it may have had the opposite effect, by creating an additional bureaucratic layer upon the existing institutions (Stemmer). Contrary to some claims, PADCT did not introduce peer review in Brazil, which had existed since the fifties. However, it may have strengthened it, since its projects were significantly more substantial and were submitted to more detailed analysis and discussion than those of CNPq.

In the early nineties, there was a trend to make science and technology more directly relevant to industrial competitiveness, in a new international context characterized by increased market competition and the growing relevance of science based industries (Guimarães, E., 1992). A few features of this trend can be listed:

- (a) the gradual extinction of market protection for computers, telecommunications, microelectronics and supplying industries;
- (b) the transformation of Finep into an agency dealing almost exclusively with the financing of industrial technology, and the gradual reduction of the National Fund for Scientific and Technological Development (FNDCT), its main instrument for supporting academic and basic research;

Box 2

What global figures do not show

Between 1985 and 1988 the federal government budget item related to general administrative expenditures jumped from 4.7 per cent to 10.4 per cent of the total expenditures for science and technology. This change reflects an increase in political patronage that takes hold of Brazilian bureaucracy at the time of the 1986 elections. At the same time, the National Commission for Nuclear Energy alone absorbs 25 per cent of this item, which was a way to provide money for discretionary expenditures for the Brazilian nuclear program. We can add to this figure the capital investments in state companies in 1988, which included the bailing out of Nuclebrás and other items marginal to science and technology as such, like airport infrastructure, debt payments, and others. The total comes close to one third of the federal budget for science and technology. This bureaucratization of science appears also in the fact that, in that year, about 25 per cent of the resources from the Ministry of Science and Technology were used for administrative activities, most of it in its central administration (excluding supervised institutions such as the Institute for Space Research). The remaining expenditures were given to applied research (33 per cent), basic research (7.7 per cent), graduate education (8.6 per cent) and fellowships (6.5 per cent). Military expenditures took a significant bite from the applied research item: 12 per cent for the old National Security Council, 8 per cent for the Armed Forces General Staff (Emfa), and 5 per cent for the Navy. Science and Technology expenditures in the Ministry of Aeronautics were classified as "basic", and absorbed a third of that item.

Botelho (1990, 1992).

(c) the increasing support and stimulus for the creation of "technological parks" near the main universities;

(d) the freezing, or reduction of large governmental R&D projects, such as the nuclear and the military aircraft programs;

(e) the establishment of a few governmental programs to stimulate quality and competitiveness in industry;

(f) the increasing concern with university managerial autonomy and accountability, and transparent rules for public financing to the sector.

Box 3

Cooperation and partnership between university and industry

The Department of Mechanical Engineering of the Federal University of Santa Catarina works in three important areas — fine mechanics, new materials and industrial automation and quality control. It has a support program for small and mid-size industries financed by Germany's Gesellschaft für Technische Zusammenarbeit, in an agreement with the Program of Human Resources in Strategic Areas of the Ministry of Science and Technology, and cooperates with the state's Secretary of Agriculture in the development of agricultural equipment prototypes, and in the development of environmentally safe agricultural technologies, which has also the support of the World Bank.

The Department has long-term contracts for research and development with many industrial firms, including Embraco, Portobello, Pirelli, Weg, Mannesman-Demag, Braun-Boweri, Volvo, Bosch, Eletrosul, Copesp, CNEM and CTA. Such contracts account for about 90 per cent of the department's research budget. Contract proposals are evaluated and priced by a permanent commission according to their technical interest. Profits from these contracts are applied to a fellowship research fund for undergraduate students. There were 234 such fellowships in 1991.

In 1984 the Department created a Regional Center for Technology Foundation (Cerci), and in 1991 it began a new project for local technological development, Tecnópolis. Both activities have the support of the state's Federation of Industries and of state and local governments. Cerci works as an "incubator" and since 1987 it generated six companies, and is nursing 15 now. The State Development Bank of Santa Catarina opened a special line of credit to finance new technologically intensive companies, which receive also tax exemption or rebates from the state and local governments.

Based on Maria Helena M. Castro (forthcoming).

Given the persistence of economic stagnation and political uncertainty in the early nineties, this new trend could not get fully established and show its effects. The reduction of FNDCT deprived many research institutions from institutional support and the ability to work properly and retain their best people. The universities suffered from budget limitations, increasing salary costs and the absence of incentives for performance and efficiency (Schwartzman, J., 1993). On the positive side, the state universities in São Paulo were granted a fixed percentage of the state's tax basis for their financing, and increased autonomy to manage their resources. In some places, like at the School of Engineering at the Federal University of Santa Catarina (box 3), the situation led to new experiences of cooperation and partnership among university departments, local and foreign governments, private firms and donors, for research and development and for the creation of new high technology firms ("incubators") (Castro, M. H., forthcoming).

3. The achievements of the seventies and the realities of the nineties

The scientific and technological competence acquired by Brazil in the last decades is an important asset for its continuous drive for social and economic modernization. There are, however, important questions and concerns about the adequacy of this system of S&T, as it was organized in the seventies, to achieve what is expected from it. Part of the difficulty lies in the persistence of the assumptions that presided the S&T policies in the sixties and seventies, when faced with the realities of the nineties; and part on the structures and vested interests created along these years.

The "endless frontier"

The basic assumptions that presided the development of S&T in Brazil during the sixties and seventies were not very different from those in the United States and other developed countries at the time. In both cases there was the notion of science as an "endless frontier", worth expanding for cultural reasons, for its beneficial effects in the quality of education, and for its promises in terms of practical applications. All fields of knowledge were equally deserving, and all good projects and initiatives should get public support. There were other resemblances: the importance given to military R&D; the notion that scientists should be funded by the State, free to control their institutions and distribute research resources according to their own criteria; and the assumption that social and economic benefits to society as a whole would necessarily derive from basic S&T in the universities and military research in government institutions (Branscomb).

Planning

There were also important differences. Brazilians believed more in comprehensive planning, and in planning for science and technology, than Americans did. There was, as there is still, a dire need for reliable information, and stable decision procedures for resource allocation and the establishment of long-term projects. The tradition was to try to fulfill these needs with comprehensive planning exercises, which could be turned into law and administered by the bureaucracy, thus making further decisions unnecessary. Three National Plans for Scientific and Technological Development were issued since the early seventies. Complex coordinating bodies (such as the Council of Science and Technology, CCT) were devised to try to link the research activities of different ministries. The Ministry of Science and Technology was created in 1985 as a response to demands from leading personalities in the scientific community, which expected it to fulfill this planning and coordinating role, making it more relevant to the country's economic and social needs. The notion that these links were to be achieved through centralized planning contributed to the development of large bureaucracies for S&T administration. CNPq and Finep increased their staff several times between the sixties and the eighties, and the bureaucratic apparatus of the new ministry also grew.

Import substitution in science

Another difference was that the development of S&T in Brazil was understood as part of a broader pattern of import substitution that was dominant in the economy, and led to barriers against foreign competition and the protection of infant industries. Although Brazil never attempted to develop a "national science", and valued its access to the scientific international community,⁵ the level and intensity of international interchanges was never as intense as that of other small scientific communities (Schott), and its research institutions and programs were seldom exposed directly to international standards of quality and evaluation. Considerations about regional inequalities and short-term needs, and political pressures for the creation of academic and research institutions throughout the country, led often to the weakening in the criteria for resource allocation by the government agencies.

Elitism in technology and education

A final feature of the Brazilian S&T development effort has been the elitism of its technology and educational policy orientations, despite the political and socially

⁵ There were several proposals to create a typically "Brazilian" social science, based on the country's peculiar historical and cultural nature, from Gilberto Freyre to Alberto Guerreiro Ramos. Nothing similar, however, ever existed in the natural sciences, except in applied fields such as agriculture, natural resources and earth sciences, as should be expected.

progressive outlook of many of its promoters. Military technology was expected to be the harbinger of economic and technological modernization, leading to a disproportionate concern in government, diplomatic and academic circles, with the international constraints on the transfer of sensitive technologies. The two PADCT programs placed strong emphasis on the higher-end, frontier technologies, with a much smaller place given to science education, management and diffusion. Except in the field of health, there were no organized efforts to bring the benefits of scientific knowledge to the population as a whole, or to the basis of the productive system. In spite of the initial influence of the American Land Grant colleges, Brazilian agricultural education and research remained restricted to a few institutions, and geared to the capital intensive, export sector of the economy (Azevedo). The recent effort to develop indigenous capability in computer science concentrated in the protection of the national hardware industry, rather than in the generalization of the use of the new technologies and competencies throughout society (Lucena; Tigre).

Table 2
Brazil, education figures: population of five years of age and above

	Brazil	Women	Rural	Northeast
Literacy (1990): can read and write (self-reported)				
five years and more	76%	77%	58%	57%
10 to 14 years	86%	89%	70%	67%
60 years and more	56%	53%	32%	44%
Educational attainment (years completed)				
Total	100%	100%	100%	100%
one or more	82%	82%	65%	65%
two or more	77%	77%	57%	57%
three or more	68%	70%	46%	48%
four or more	59%	60%	34%	39%
five or more	41%	42%	17%	28%
six or more	33%	34%	11%	22%
seven or more	29%	30%	9%	19%
eight or more	25%	26%	7%	16%
nine or more	18%	19%	4%	12%
12 or more	6%	6%	1%	3%
total (thousands)	113,629	58,373	28,011	31,614

Source: Fundação IBGE, *Anuário Estatístico*, 1992.

In education, Brazil tried to generalize the university research model before any serious attempt to deal with the problems of basic, secondary, technical and mass higher education. In consequence, the country has, simultaneously, some of the best universities and graduate programs, and one of the worst and unequal systems of basic education in the region. In practice, the university research model remained restricted to a few public universities in the São Paulo and in the federal system. Most other public institutions incorporated the institutional features and costs of modern universities (including full-time teaching, departmental organization, integrated campi, besides free tuition), without adequate mechanisms for quality assurance and the efficient use of public resources. About 65 per cent of the students in higher education do not have access to public institutions, and attend the less prestigious, paying private institutions (Goldemberg, 1993; Schwartzman, Durham & Goldemberg, 1993).

Brazil had always been a highly stratified and unequal society. Even when the intention was there, governments had faced enormous difficulties in reaching the broader population with services like education, health and extension work. This situation should be reversed, but this does not mean that efforts to create good universities and competent research groups should be postponed until the problems of basic, technical and secondary education are solved, since these skills and competencies are essential for carrying on the needed transformations. It would be a mistake, however, to suppose that scientific, technological and educational investments could not have had a broader impact on professional education and the dissemination of general and technical competence than they did. They can, but specific policies are needed for that.

4. New realities

Changes in the role of science and technology in the international scene

The international scene for science and technology has changed dramatically since Brazil begun its drive for S&T development in the sixties. The main features of the new context can be described as follows:

Science and technology are much closer to industry and markets than before (box 4). Industries depend, for the development of new management skills, processes and products, on specialized knowledge that cannot be generated anymore, as a matter of course, in their daily activities. The consequences have been an increase in R&D investments, the setting up of specialized laboratories and research departments, and the search for new links with universities. There is a renewed concern with the problems of intellectual property, which occurs in association with an expanded knowledge industry, carried on through licensing, technical assistance projects and international consulting.

Box 4

Fundamental and economically relevant research: the new links

In all industrial countries, governments have tended to shift, in recent years, to indirect actions intended to promote the development of a trade-oriented research environment: legislative and regulatory measures considered to be obstacles to the diffusion and application of knowledge have been lifted (for example, various anti-trust regulations were removed in the United States to facilitate pre-competitive research co-operation between firms); new rules were adopted to encourage scientists to take a more active interest in the exploitation of their work (for example by allowing academic research-workers and institutions to apply for patents, even when the invention had been the result of federally sponsored programs, or by relaxing academic rules so that professors could participate in commercial ventures); incentives multiplied in order to promote science-based industrial activities (i.e. fiscal incentives, schemes to develop employment of scientists by firms of all types, research funding instruments for industry-university collaborative ventures, and so on).

This focus has been accompanied by gradual re-direction of the public research support towards new types of programs, in order to channel efforts onto areas of greater economic relevance. This has affected all types of research activities. For example, institutions that have traditionally been bastions of fundamental research (from the CNRS in France to the National Science Foundation in the United States) devote more and more attention to applied research and strategic research justified by its economic implications. Pre-competitive research activities have multiplied to bring together academic and industry scientists. Certain disciplines receive renewed attention and expanded support, when they relate to the "sciences of the artificial", or "transfer sciences", ranging from mechanical and chemical engineering to medicine and pharmacy. And economic relevance increasingly becomes an essential yardstick in the assessment of research proposals everywhere.

Georges Ferné.

The pace of technical innovation and competition in industry has accelerated, requiring from firms a permanent capability to change its organization, absorb new technologies and processes and generate new products. This is leading to significant changes in the composition of the industrial labor force, with more emphasis given to highly skilled and motivated workers at all levels, and drastic reductions in administrative personnel and non-qualified employees. Consequences of this acceleration of the pace of technical progress and intensification of market competition include the growing internationalization of industries and markets and the redefinition of production lines, with specialization in some segments of the production chain, or in some market niches. New associations and mergers, very often with companies from different countries, are also prompted by the high financial costs of R&D and the shortened life-cycle of new products.

Box 5

Major changes in American S&T policies

Americans now understand that the world has radically changed. But the paradigms on which the post-war S&T policy consensus rests are still firmly planted in many people's heads, especially in Washington, and the institutions of government that will be needed to implement a new consensus have changed hardly at all. But three major changes in the US will require not only a rethinking of technology policy, but changes in institutions and new international linkages as well:

(a) recognition that defense priorities will no longer dominate the US federal government's technology policy. Instead defense must face a drastically shrunken production and weapons acquisition base, will have to increase the fraction of the defense budget devoted to exploratory development and prototyping, even as the defense R&D budget decreases. Because the technologies critical to the new force structure will increasingly fall into areas in which commercial industry is ahead of defense industry, especially the information and communications technologies, defense agencies will have to gain access to commercial technologies. This will require radical change in defense acquisition policies and practices;

(b) recognition that progress in modern, science-based engineering depends increasingly on a publicly-provided infrastructure of basic technical knowledge, tools, materials, and facilities. Between the realms of basic science and proprietary technology there lies a large domain of public good technology, whose value in application is clear but in which firms underinvest because of low appropriability of the benefits. Much of this "infrastructural technology" supports the creation and improvement of design and process technologies. Such capabilities concurrently support military, commercial, and environmental goals. But reliance on "spin-off" from mission-oriented government R&D, on generation by hard pressed private investors, and on technology-forcing through administrative and tort law does not provide the nation with the long term capability to remain both a technological and economic leader. In short, we need a publicly supported technology base, supporting industry's capability to create technologies for all three areas of national need;

(c) recognition that economic performance in a competitive world economy rests primarily on how well the society uses the existing base of technology, skills, and scientific understanding, and only secondarily, and accumulated over time, on annual additions to this stock of capability. It follows, then, that the government's technology policy must give much greater emphasis to the diffusion of technical knowledge and skills. The primary elements of a diffusion strategy are: aggregating, evaluating, communicating, and absorbing non-proprietary information. The primary mechanisms are through education, mobility of technical personnel, and networks (both facilities and institutions) for promoting cooperation and sharing. The states, as well as federal agencies, have major responsibilities here, especially for industrial extension services.

Lewis Branscomb.

Science is becoming more global. The speed, quality and low cost of international information flows bring researchers and research sites into immediate contact. The spreading of technological products and processes by international firms disseminates similar patterns of consumption, organization and work. It is much easier now to have access to the international scientific community than in the past, and the international mobility of talented researchers was also simplified. Simultaneously, there are increasing entrance requirements in terms of the standardization of scientific instruments, language and patterns of communication, leading to new inequalities and concentration of resources and skills.

As the economic and military importance of scientific and technological knowledge increases, there is a growing tendency to limit its diffusion through legislation on intellectual property and governmental barriers to the diffusion of "sensitive" technologies. This tendency, however, is offset by the intense international competition of firms and governments to sell their technologies, and by the lack of well-defined boundaries between academic (and therefore free) and proprietary knowledge. The net result is that the bulk of modern technology is available for countries with the necessary pool of competence in engineering and basic sciences, except for a few military items that can still be controlled by the main powers.

More recently, the end of the cold war is forcing the major powers into a difficult process of downsizing their military establishments, which is altering the traditional association between military R&D, industrial technology and basic academic research. Part of these resources will move to applied fields like health, the environment and energy, and new associations between government, research institutions and private corporations are likely to emerge. In these countries, scientific innovation in the new, civilian dominated context will be likely to be driven by markets and short term social demands, rather than by government "requirements"; to be more incremental; more closely related to manufacturing and service; and more cost-conscious than in the previous years (box 5).

Changes in the nature of the scientific enterprise

The "simplest linear model" of scientific development and technological change is being abandoned. It assumed the existence of a pattern of fundamental research yielding discoveries and leading to the experimental findings of applied science, which allowed for acts of invention, which provided the basis of entrepreneurial innovation, creating new products and processes, which were later diffused by imitation and reverse engineering (David, 1992). The current view is much more complex. Scientific discoveries often take place in the context of application; there is no clear-cut distinction between basic and applied work; tacit knowledge and incremental improvements are more important than isolated scientific breakthroughs. One consequence of this changing perspective is that sup-

port for basic research has lost ground, when not linked to identifiable products and results.

The development of new patterns of international scientific cooperation, with the establishment of large-scale international ventures such as the Human Genome Project and global research activities in the fields of meteorology, global warming, astrophysics, and regional cooperative projects. While traditional "big science" programs, such as the European Consortium for Nuclear Research (CERN), were characterized by large scientific installations, the recent ones tend to be organized in terms of extended and closely linked networks of scientists and research groups. For small scientific communities, the alternatives are either to participate in some aspects of these ventures, or to lag further behind (box 6).

Box 6

European cooperative projects

Eureka projects:

- 646 projects in nine areas: medical and biotechnology, communications, energy, environment, information technology, lasers, materials, robotics and production automation, transport.
- EU 95: High Definition Television, 1986-93; budget: US\$750 million.
- EU 127: Joint European Submicron Silicon Programme, 1989-96; budget: US\$4.6 billion.

European community projects:

- Framework III Programme, 1990-94; 12 member countries, precompetitive research; total budget, US\$7.99 billion.
- DGXII: science, research and development. Brite/Euram: industrial and materials technologies, plus other research programs.
- DGXIII: information technology and communications. Race: communication technologies; Telematics: information exchange.
- DGIII: industry. Esprit (moved from DGXIII).

Science, 1993.

Because of its increasing costs, economic benefits and potential dangers, science and technology activities are more closely watched by society than in the past. Public controversies blur the frontiers between technical expertise and common knowledge, and a host of new activities and disciplines linked to scientific assessment have emerged, dealing with questions like technological forecasting, technology assessment and the evaluation of environmental effects of innovation. The social sciences have acquired new relevance in this context, in the study of

the economics of science and technology, the understanding of the social processes of education and knowledge production, the interpretation of public controversies, and in the analysis of public policy-making related to the field of S&T.

The traditional organization of the scientific enterprise is under criticism. The division of academic departments and scientific institutions along disciplinary lines is being questioned on its ability to provide the proper training and conditions for interdisciplinary research. At the same time, there are no clear alternatives to the conventional organization of teaching and education along disciplinary lines, bringing a further source of tension between teaching and research. Government agencies for science support are being revised and transformed. The links between universities, government and industry are deeply changed by new patterns of technical education, cooperative research and financing, generating new opportunities and tensions. Traditional scientific careers are perceived as less rewarding, prestigious and secure than in the past, while new professional patterns emerge.

Changes in the nature and capabilities of the Brazilian State

Brazil, which presented one of the world's highest rates of economic growth until the seventies, did not adapt to the changing international environment of the eighties, and entered a prolonged period of economic stagnation cum inflation from which it is still to recover. Different explanations are given to this fact, going from the exhaustion of the import substitution model that characterized the country's economy since the thirties, to the political and institutional inability of governments, since the eighties, to carry on long-term policies, in a context of international hardship and intense political competition for public subsidies. There is a clear notion, today, that the State has to reduce its size and its presence in the economy, while gaining competence to set and carry on long-term policies of economic growth, social welfare and environment protection. It is not clear, however, how this change should affect the S&T sector.

This situation of instability and lack of vision affected the S&T sector in two important ways. The most obvious was the reduction of resources for most existing programs, and the lack of perspectives for new projects and initiatives, even when international commitments, such as the loan contracts with the World Bank and the Interamerican Development Bank, required well defined matching funds according to prescribed timetables. Probably more important were the problems of institutional and financial instability. The Ministry of Science and Technology changed name and status several times, budgets allocated to R&D institutions oscillated, and the actual delivery of these funds depended on constant, painful and daily negotiations with often unsympathetic economic authorities at the lower ranks in the bureaucracy. Not only resources were limited, but there was no consensus in government, public opinion, or international agencies, about the importance and role of scientific research, or about matters like basic *versus*

applied, civilian *versus* military, academic *versus* industrial research. This instability has been a matter of great concern, given the long time it takes for scientific institutions to mature, compared with the speed in which they decay in conditions of budgetary and institutional insecurity. In the early nineties, the state of Brazilian science and technology can be summarized by the following points.

The federal agencies for science and technology support (Finep and CNPq) are very limited in their ability to grant resources for research projects. Most of CNPq's resources are used for fellowships, while Finep is specializing on loans to technology projects in the private sector. On the other hand, São Paulo's Foundation for Research Support (Fapesp), was preserved as an efficient and prestigious institution, and even increased its share of the state's main tax revenue (from 0.5 to 1.0 per cent), supposedly for applied work and industrial development. Several other state-level research support institutions were created in the late eighties, but few are active and efficient.

The administrations of some federal agencies for S&T suffer the effects of swelling bureaucracies, low salaries and political militancy of their employees. Others, on the contrary, are understaffed, and unable to hire adequate persons to fulfill their functions. CNPq has been particularly affected by a permanent tension between its employees and the council's academic advisory bodies. Most federal research institutions, including the research institutes under CNPq, are paralyzed by lack of resources and incentives.

There is no consensus about what to do with the large-scale projects of the past, which are in large part paralyzed by lack of resources. The military doctrine of technological development from the seventies seems intact within the Armed Forces, in spite of the current constraints. None of the large projects was discontinued — the atomic submarine, the space project (including the development of rockets and satellites) and the construction of military airplanes. The space project is moving from military to civilian control, and the government has sent a bill to Congress to create a Brazilian Space Agency, which would consolidate this transition (Cavagnari).

Benevolent legislation allows for early retirement (at the age of about 50), with full benefits, of many professors in public universities and the civil service. About 30 per cent of current expenditures in the federal universities are used for retirement benefits, and this figure is growing. Lacking information, it is difficult to know how this is affecting the pool of active researchers, whether they are continuing their activities in other (and sometimes the same) institutions, and how they are being replaced. The general perception is that the private benefits of early retirement, combined with the instability and low prestige of many teaching and research institutions, are depleting Brazil's active scientific community. While this situation does not change, it is important to stimulate the retiring, well-qualified professors to remain productive in other roles, starting for instance new careers as entrepreneurs. Retirements should be used also as an opportunity to open the vacancies to a new generation of young academics and researchers.

Box 7

Activities of the Ministry of Science and Technology, 1993

1. Permanent activities carried on by MCT or with its support:

- (a) large projects involving investments in basic infrastructure;
- (b) research projects in the basic, natural and social sciences;

(c) technology development projects in the fields of biotechnology, with emphasis on genetic engineering and its applications; in new materials, including microelectronics; in chemistry, including the synthesis of natural products, all with strong impact in the modernization of the productive system.

2. Regional programs, like the weather and climate forecast projects for the Northeast and the Center-South regions.

3. The definition of new legal and financial instruments for the S&T sector:

- (a) incentives for industrial investment in R&D;
- (b) rules for the implementation of the informatics and the Amazon Free Zone legislations;
- (c) utilization of resources derived from the privatization program for strategic projects such as the Satellite Launching Vehicle, the supercomputer of the National Laboratory of Computer Sciences, the National Laboratory of Synchrotron Light, the National Laboratory of Nuclear Physics, the research program in the Antarctic region and the survey of natural resources in Brazil's continental shelf;
- (d) creation of the National Commission for Industrial Technological Qualification;
- (e) establishment of the program for software production for the international market;
- (f) writing and follow up of new legislation for the S&T sector: for patents, software, vegetal diversity, topography and integrated circuits, trade of sensitive technologies, and the creation of Brazil's space agency.

José Israel Vargas (1993).

Within these extremely adverse conditions, the Ministry of Science and Technology is trying to put forward some ideas and policies for the sector (box 7). One of its main tasks has been to assure a regular flow of budgetary and non budgetary resources to the sector. The proposal for the federal budget is to

obtain between US\$1 billion and US\$1.5 billion for the activities under the Ministry of Science and Technology for 1994. The government has decided that a substantial part of the resources obtained through the privatization of public companies should go to the science and technology sector; and recent legislation granted tax benefits to firms engaged in technological development. The official expectation is that these two sources alone could double the resources for science and technology for 1994. The ministry is also engaged in continuous negotiations with economic authorities for the stabilization of the flux of resources to the agencies, and with international institutions for continuing or renewed support for the S&T sector. The second goal of the ministry is to continue and conclude some of the large projects that have already started, and are stalled for the lack of resources. The two most preeminent are the space and satellite program and the laboratory of synchrotron light. The ministry has also proposed a bill establishing a unified career structure for researchers and employees in federal institutions. In the Ministry of Education, Capes, the agency for high level manpower education and training, maintains a stable line of fellowships and support for graduate programs. Some projects created during the Collor period (1990-92) to stimulate quality and competitiveness in the industrial sector are still in place, although with very little resources to go on.

Box 8

The internationalization of trade, business and technology

The internationalization of trade, business and technology is here to stay. This means that national borders means much less than they used to regarding the flow of technology, at least among the nations that have made the now needed social investments in education and research facilities. National governments have been slow to recognize these new facts of life. Indeed, the last decade has seen a sharp increase in what has been called "techno-nationalism", policies launched by governments with the objective of giving their national firms a particular edge in an area of technology. Our argument is that these policies to not work very well anymore. It is increasingly difficult to create new technology that will stay contained within national borders for very long in a world where technological sophistication is widespread and firms of many nationalities are ready to make the investment needed to exploit new generic technologies. A closely related observation is that a well-educated labor force, with a strong cadre of university trained engineers and scientists at the top, is now a requirement for membership in the "convergence club".

Nelson & Wright (1992).

5. A new policy for a global world

In spite of the large science and technology gap between Brazil and the leading industrial nations, there might be an opportunity for convergence that should not be missed. Access to international information is cheap; circulation and mobility of scientists are intense; technologies for products and processes are offered in a highly competitive international market; multinational corporations spread their branches and research facilities throughout their world, depending on local conditions. The main requirements to seize this opportunity and share these knowledge resources are the country's social capabilities, which are essentially a matter of education and scientific competence (Abramovitz, 1986; Nelson & Wright, 1992; box 8). While science and technology are becoming more internationalized, the requirements to participate in their benefits remain local and national, and depend on purposeful efforts from local and national governments.

The main thrust of this policy paper is that there is a definite need to move from the previous mode of scientific and technological development into a new one, more adequate to the current and future realities. Science and technology are more important than ever for Brazil, if the country is to raise the standards of living of its population, consolidate a modern economy, and participate as a significant partner in an increasingly integrated and global world.⁶ The economy must modernize, and adjust to an internationally competitive environment. Education should be expanded and improved at all levels. As the economy grows and new technologies are introduced, new challenges will emerge in the production and use of energy, environment control, public health, the management of large urban conglomerates, and changes will occur in the composition of the labor force. Strong indigenous competence is necessary to participate as an equal in international negotiations with important political and economic consequences for Brazil, in areas such as the protection of intellectual property and rights of access to information, norms of environment control and the establishment of technical standards in international communication networks. A traditional, *laissez-faire* approach to scientific and technological development will not produce the necessary competence on the scale and quality needed for these tasks, and will not make them as useful as they can be. There is little place left for protected technologies under artificial conditions, and large-scale, sophisticated and highly concentrated technological projects are not likely to spin off into education and industrial development as a whole. Attempts to bring the whole field of science and technology under the aegis of centralized planning and coordination run the

⁶ The term "global" conveys the notion of an interdependent world civilization, with permeable boundaries and no clear hegemonic centers. There is a growing literature on the global nature of modern societies. See for instance Albrow & King, 1990; Robertson, 1992; Featherstone, 1992; Wallerstein, 1990.

risk of stimulating large and inefficient bureaucracies, and to stifle initiative and creativity.

The new policy should implement tasks that are apparently in contradiction: to stimulate the freedom, initiative and creativity of the researcher, while establishing strong links between their work and the requirements of the economy, the educational system and of society as a whole; and to make Brazilian science and technology truly international, while strengthening the country's educational and S&T capabilities. To achieve this, the individual researcher, and their research unit or laboratory, should be freed from bureaucratic and administrative constraints, and stimulated to look for the best opportunities and alternatives, in the country and abroad, for the use and improvement of his competence. This requires, in turn, a competitive environment based on public incentives and private opportunities that rewards achievement, increases the costs of complacency and underachievement, and gears a substantial part of the R&D resources toward a few important and strategic selected goals. More specifically, the new policy should include the following tasks:

(a) to increase the links between academic science and the productive sector, and to increase the share of the latter in the national effort for scientific and technological development, approaching the patterns of the modern, industrialized economies, where most of the R&D effort takes place in the productive sector. This requires a significant increase in private investments in R&D, not a reduction of the already limited public funds;

(b) to create two different "markets", one for academic science, another for applied technology. The academic market needs a system of rewards and incentives for scientists, appropriate career structures, and means to increase public support for science. The market for applied technology should combine the requirements of competence and quality with those of economic feasibility and social need;

(c) to increase the links between science, technology and education, from the graduate programs down to technical and basic education;

(d) to invest heavily in the development of innovative capabilities of the productive system as a whole, through incentives, extension programs and the strengthening of the country's infrastructure for basic technology;

(e) to support a few integrated projects of clearly identified social and economic relevance and in need of S&T research and education, in areas such as energy, environment preservation and control, transportation, public health, food production, and in social fields such as basic education, poverty, employment and the

management of urban conglomerates (Goldemberg, J., 1993; Skole & Tucker, 1993; Castro, N.A.);

(f) to create the conditions for Brazil's participation in international programs dealing with global issues;

(g) to make the government agencies for science and technology more flexible and bound to peer review procedures, and to stimulate research groups and institutions to search for partnership and support from a variety of sources and through different procedures, beyond what governments can provide and do.

6. Policy recommendations

To achieve these goals, the following recommendations are made:

To redirect the country's technology policies in line with the new economic realities

Box 9

Technology transfer: the new economic policy orientations

Regarding the transfer of technology from abroad, it is necessary to preserve and consolidate the economic policy orientations introduced in the nineties, aimed to remove existing obstacles and restrictions affecting the main transfer channels — the import of capital goods, technology contracts and foreign investment. It is necessary to go further regarding the use and diffusion of foreign technologies incorporated in capital goods, with the liberalization of import mechanisms for equipment, and the reformulation of the informatics policy. It is also necessary to proceed with the revision of the traditional administrative procedures for the registration of technology transfer contracts. These practices amounted to strong government intervention and restrictions in the transference process. In the same vein, policy changes in the informatics sector, eliminating restrictions to the presence of foreign companies and the establishment of joint-ventures, helped to remove a significant block to technological transfer, which was specially important because it affected precisely the industrial sectors where technical progress is more intense.

Eduardo A. Guimarães.

Box 10

Recommendations about the patent law

— Some changes, such as the concession of patents to pharmaceutical products and process, are unavoidable to normalize Brazil's international economic relations.

— The new legislation should be based on the text being negotiated within Gatt, as it is the case of the proposal put forward by the Interministerial Group. American pressures to include the patenting of life forms and the "pipeline" do not correspond to internationally accepted rules as yet. In addition, no short-term agreement of free trade with the United States is being considered, to justify such concessions. A rapid approval of a new legislation without transition adjustment periods for specific industrial sectors would attend, in general terms, American demands.

— Industrial property is just one policy instrument for science and technology. Investments in research and development, institutional environments and a competitive context are more important for scientific and technological development than patent legislation.

— The revision of the Code of Industrial Property should not be interpreted as a way to attract direct foreign investment in research and development. This revision is required above all by the need to stabilize Brazil's international economic relations, specially with the United States.

— Patents are important as an asset in the competitive strategies of firms. In this sense, it is important for sectors that are potentially more dynamic in terms of new technology generation, such as biotechnology.

Patent legislation, in short, should not be confused with "nationalism" or "isolationism". The revision of the Code of Industrial Property is an unavoidable consequence of the current international scenario.

Lia Valls Pereira.

Technology policies are needed to make it possible for the country to enter a new pattern of industrial growth, centered on increasing levels of competitiveness. On the short run, the policies should be geared to the reorganization and technological modernization of the industrial sector. Then, permanent policies should exist to induce the more dynamic sectors of the productive system to enter a continuous process of innovation and incorporation of new technologies, to follow the rhythm of technical progress in the world economy (box 9). Both approaches require, as the main priority, the incorporation of existing technology to the productive process. Sectorial policies are needed for the reorganization and

technological modernization of less efficient parts of the economy, and for the consolidation and expansion of the more dynamic industrial sectors. Support for research and development activities should be selective, and clearly associated with broader processes of innovation based on the transfer, diffusion and absorption of technological competence.

Box 11

Financial stability and the PADCT

Financial stability is essential for reaching results, specially for experimental laboratories. There is no point in granting resources to buy expensive equipment if there are no additional resources for installation, operation and maintenance, and more specifically for hiring and training technicians to operate it. Large time lags occurred frequently within PADCT between the arrival of equipment and the availability of operational resources. Difficulties to import equipment created absurd situations in which projects were to be carried on in one or two years, but the equipment arrived two or three years later, when there was no money left for installation, salaries, training and operation.

Long-term programs are needed, specially for centers of excellence. Projects could be approved for several years, with a firm commitment for the first year and additional payments pending on periodical reports, evaluations and the availability of resources. Each year, the researcher would submit a progress report and an annual budget for the following period. In theory, if resources did not exist, the agency would not approve the extensions. In practice, even if budgets are reduced, there will be always some resources for the maintenance of the most important projects. Contracts should spell out clearly that long term financial commitments may not be fulfilled if the agency's budget is reduced in the future. A substantial part of the projects should be made for the long term, that is, for more than three years.

Requests for continuation and extension of existing projects should always be considered, even if they do not fit the terms of the bids being analyzed at the time. Such requests should provide a careful report about the results achieved with previous grants.

Caspar E. Stemmer.

The issue of protectionism *versus* market competitiveness in scientific and technological development should be dealt in pragmatic, rather than in ideological terms. It is impossible, and it would be tragic, to shield the country from the technological revolution that is taking place in the world. A key element of this

revolution is the role of multinational corporations and international trade in the development and diffusion of modern technologies, which makes the issues of technological development and international trade so intertwined. At the same time, a country should not renounce to its instruments of technological and industrial policy, including tax incentives, tariff protection, patent legislation, government procurement and long-term investments in technological projects, in association with the private sector. The aim of these policies should be always to improve the country's scientific and technological competence, and reap the benefits of increased efficiency, productivity and trade. In this context, adequate legislation for patents and intellectual property should be established, with the understanding that they are necessary for the normalization of Brazil's relations with the industrialized countries, although, on itself, such legislation could neither guarantee nor jeopardize the technological advancement of Brazilian industry (box 10).

To protect the existing pool of scientific competence

Many of the best R&D institutions and groups are being dismantled by absolute lack of resources, and emergency measures are needed to deter this process. The government should guarantee a stable and predictable flux of resources to its main S&T agencies for their daily routines and "over the counter", peer reviewed research supporting activities. The problem is not just of limited resources, but above all of lack of institutional stability and commitment with the sector, since the resources needed is not very high. Special programs like the PADCT could be used for this purpose (box 11).

Not only the agencies need to have their resources, but the most qualified research institutions and groups should be preserved in their ability to keep their best researchers and their work. There is a proposal being discussed for several years to establish a network of laboratories and research groups to be supported by government through long-term grants based on past performance ("laboratórios associados"), which requires prompt implementation. Estimates of size and cost of such a network vary, but the scale of the operation is not too difficult to determine. Of the estimated 15,000 active researchers in the country, about a third, or 5,000, could be included in 200 such "laboratories" of 25 persons each, supported with US\$1 million a year in average, or US\$40,000 per person, US\$200 million in total. This would be the cost of keeping the pool of competence in place, providing a basis from which other policies can be devised. A similar amount will be needed to provide these laboratories with basic equipment and infrastructure. Most of this money is already being spent as salaries by universities and other government agencies, so that the cost of this program would be even less (although the resources for research and infrastructure should be provided in addition to what is needed for regular graduate education). Ideally, the program should compensate for oscillations in salaries, guarantee resources for current expenditures, and provide

means for the acquisition and modernization of scientific equipment, regardless of the group's institutional location. Resources should be allocated competitively, under strict peer review evaluation, and for limited periods (typically three to five years). The criteria for allocation should be the laboratories' track records, the quality of their researchers, their ability to get funds from other sources, and their long-term perspectives and projects.

This network of research laboratories should be strengthened by a specific line of support for individual scientists, allowing them to move around to find the best places to use their competence; laboratories could be rewarded for the quality of people they can attract.

A competent and prestigious peer review procedure is essential for the project of "laboratórios associados" to work. On the long run, difficult problems of choice between equally competent groups and proposals may appear, requiring decision procedures that go beyond traditional peer review. However, given the current small size of Brazil's scientific community, most competent groups are likely to be supported, without increasing the historical levels of expenditure.

To develop a three-pronged policy for S&T development, with clearly distinguished support mechanisms for basic science, applied work and extension and education

The fact that basic science, applied R&D and high level technical education are very often indistinguishable, and take place simultaneously in the same institutions, does not mean that they should not be treated separately in terms of their supporting mechanisms, working from different perspectives and with different approaches.

Basic science research and education

Basic or academic science, broadly understood as research work that does not respond to short-term practical demands, remains necessary not only for its eventual role as the source of privileged discoveries for applied work, but because of its nature as an indispensable public good. Scientists should be trained on a broad fundamental basis, so that they will not become obsolete in a short time. This purpose is not in contradiction with applied work, but should not be jeopardized by too much emphasis on efforts to help solve short term operational problems of the productive sector. In spite of the growing presence of proprietary knowledge in modern societies, academic science is also expanding, and the resources it can expect from the private sector are not very high.⁷ The informa-

⁷ Only about 15 per cent of the resources for "public good" research in the United States comes from the productive sector (Aron Kupperman, private communication).

tion basic science generates is free for the private sector (although it is paid by society as a whole), and is the main source for the acquisition and spreading of the basis of tacit knowledge that permeates the whole field of science, technology and education. For a leading country, heavy investments in basic science can be thought of as problematical, since their results can be appropriated by other countries and regions for very little cost. For the same reason, investments in basic science in small scientific communities can be extremely productive, since they allow tapping the international pool of knowledge, competence and information. This is the rationale for projects such as the National Laboratory of Synchrotron Light, now under construction by CNPq (box 12).

Box 12

Basic research: the Laboratory of Synchrotron Light

The source of synchrotron light that is being built at the National Laboratory of Synchrotron Light (LNLS) in Campinas is a large undertaking with a strong interdisciplinary content. The equipment consists of an electron accelerator and a storage ring. Electrons circulate at high speed producing electromagnetic radiation of high intensity, covering an extensive energy band. This radiation can be used for different purposes, from basic research in solids, atoms, molecules and biological materials to different applications such as photolithography for the fabrication of highly integrated electronic circuitry. The light source is being built by a well-coordinated team of physicists, engineers and technicians, using many components developed in association with national companies. About US\$11 million have been invested so far in the project. It is the first Brazilian experience of building and, later, operating a large physical laboratory to be used by researchers from the whole country. Its success or failure will have important consequences regarding future decisions to go ahead with other large projects. The total estimated cost of the light source is US\$35 million.

Sérgio Resende.

Besides its eventual impact on the productive sector, basic science can play a fundamental role in enhancing the quality of higher education for engineers and for society as a whole. This role, however, does not take place as a matter of course. Universities have to develop explicit links between their graduate and undergraduate programs; intellectual and financial investments have to be made for the development of materials for science teaching, from handbooks to educational software and experimental kits. When these links and investments exist, basic science becomes more legitimate, and more likely to be supported by society.

Changes are also necessary in scientific and graduate education. Master degree programs should be shortened, and turned either into well-organized courses of professional specialization, or short entrance and leveling programs leading to doctoral degrees. Non-degree, specialization courses should be stimulated, with very little bureaucratic formalism, and as self-supporting as possible.

Globalization requires a profound rethinking of the old dilemma between scientific self-sufficiency and internationalization. The experience of small, high-level scientific communities in countries like Canada, Israel, the Netherlands and Scandinavia, shows that this may be a spurious question. They build their competence through a purposeful effort to be present in the international scientific scene, by the extensive use of the English language, participation in joint research projects, evaluation of their research activities by scientists from other countries, and a constant international flux of students, researchers and information; they are not less developed, and their science less relevant for their societies, for that reason.

The current fellowship programs of Capes and CNPq for studies abroad need to be revised. Fellowships should be awarded only to first-rate students going to first-rate institutions, and with a clear perspective of returning to productive work in Brazil. Fellowships for doctoral degrees should be combined with "sandwich" fellowships for doctoral students in Brazilian institutions, and short-term support for training periods in laboratories and companies abroad. Procedures should be devised to constrain the beneficiaries to pay back the money received if they fail to get their degrees or to return to their institutions; fellowships for countries and institutions with poor records of academic achievement for fellows should be avoided. Under these conditions, the current number of fellowships awarded should be maintained and even expanded. The existence of good quality doctoral programs in a given field does not preclude the need to keep a permanent flux of students to the best foreign universities. Provisions should exist for post-doctoral programs both abroad and in Brazil, and to bring top-quality scholars from other countries for extended periods, or even permanent appointments, in Brazilian university and research institutions (De Meis & Longo, 1990).

Applied science

The central feature of applied science is that it has a user, and the knowledge generated in the R&D process tends to be proprietary. The main clients for applied science in Brazil have been the military, the large state-owned corporations and a small section of the private sector, including the export-driven agricultural firms.

Box 13

Multi-client program in forestry research

The Research Institute of Forestry Research (Ipef) of the School of Agriculture Luiz de Queiroz, São Paulo University, was created 25 years ago in Piracicaba, bringing together five private companies, Champion, Duratex, Rigesa, Industrial de Papel Léon Feffer and Madeirit, to deal with questions of common interest. Today, there are 23 associated companies, and the results have been surprisingly good. The average productivity of wood, which was around 15m³/ha/year, is now about 30m³/ha/year for the companies associated to Ipef. The institute has contributed to this increase in productivity through basic research and education and training of personnel for the companies. Its germ research center, recognized by UN's Food and Agriculture Organization, is the largest in the southern hemisphere in genetic materials, and commercializes about three tons of seeds each year, exporting to countries like Indonesia, Venezuela and Thailand. As an example, 300kg of seeds from *Eucalyptus urophylla* were sold recently to Indonesia, which is the country from where this species originates. The associated companies are located in the states of Bahia, Minas Gerais, Espírito Santo, São Paulo, Pará, Paraná, Rio de Janeiro, Santa Catarina and Rio Grande do Sul. This model of association was followed by other institutions. Today, besides Ipef, there is the Fund for Forestry Research in Curitiba, Paraná (Fupef) and the Society for Forestry Investments in Viçosa, Minas Gerais (SIF). Research takes place also in state research institutes such as the São Paulo Forestry Institute, which sells about 23 tons of seeds yearly.

João Lúcio Azevedo.

Applied R&D should be evaluated in terms of its short-term scientific quality and medium or long-term practical results. When the client is a public institution, such as the military or a state-owned corporation, R&D projects tend to be secretive, large and long-term. Evaluation is very difficult to carry on, since research results are not open to publication, peer review scrutiny, or market competition (Erber). Lacking appropriate evaluation procedures, applied R&D in the public sector runs the risk of being expensive and of doubtful quality, the same holding for publicly-subsidized R&D in private firms.

There is a clear trend away from these kinds of R&D activities, however. In the current international context, there are limits on what smaller and poorer countries can do in terms of military prowess. In contrast, there is a strong premium on the spreading of education, technical competence and competitiveness through society. Most public corporations are either being privatized or forced to rely on market mechanisms to survive. In both cases, publicly subsidized applied R&D will tend to diminish. The Brazilian experience of subsidized R&D to the

private sector is not very good. If loans are granted below the market interest rates, there may be many takers, but the outcomes are often poor. There is a room, however, for special procedures to finance long-term and joint R&D projects that would not otherwise find support through commercial banks. General policies and support mechanisms for applied R&D are difficult to devise, since they refer to an extremely variegated range of activities, and require different combinations of economic, scientific and strategic considerations. A few suggestions, however, can be made:

Research groups in universities and government institutes should be strongly stimulated to link to the productive system and to engage in applied work, while maintaining a high level of academic and basic research activities. It is as unwarranted to expect that all basic science should be linked to production as to assume that they should be kept isolated from each other. There is no reason to believe that applied work would necessarily distract researchers from their basic and academic oriented activities. However, tensions and conflicts of interest may arise, and need to be administered case by case. Links between academic research and the productive system can take place at multiple levels, depending on the capabilities and needs of each side. They can go from help in the solution of short-term problems and difficulties faced by industries, to the transfer and scaling up of innovations produced by research centers for industrial production; and, at the higher end, to the development of large scale, cooperative projects of R&D (Frischtak & Guimarães, 1993). Links can be established either with single institutions or with associations and consortia of users, as in the example of the Institute of Forestry Research of the Universidade de São Paulo (box 13). Resources for applied work should not come from the budget for basic activities, but from specific sources in governmental agencies, special programs, private firms, and independent foundations.

Government agencies dealing with matters requiring research work, like in health, education, environment, energy, communications and transportation, should have resources to contract research in universities and research institutions on matters of their interest. This practice should prevail over the tendency of these agencies to create their own research outfits, and their projects should be subject to joint evaluations by peer review and policy oriented authorities. Research institutes and centers in public agencies and state companies should be placed under peer oversight, and required to compete for research support outside their agencies.

The current military projects should come under technical, academic and strategic evaluation with the participation of selected, high quality scientific advisers, and be either streamlined, discontinued, reduced, or converted to civilian projects (box 14).

Box 14

Military research and competitiveness

The goal of making Brazil a world power can only be achieved if the country can survive and develop in a competitive international environment, which depends on the non-military components of its strategic capabilities — mainly its scientific and technological capability. In consequence, the country's efforts should be directed to this goal, without giving priority, necessarily, to military R&D. There is no doubt that the main current military projects should be continued until their completion, but the perspectives of military R&D regarding the more advanced technologies is limited, given the tendency of civilian R&D to administer such technological projects as efficiently as the military.

The difficulties found in the development of military programs could be reduced if the development of higher end technologies is not militarized. This, however, does not mean that the Armed Forces should be excluded from research and development activities. On the contrary, they should continue to participate in this effort, but aware that the country's prestige, as well as the strengthening of its strategic capabilities, will not come only from its military prowess, but above all from the competitiveness the country can achieve in the international system. Countries that can compete will be strong. The bases for competitiveness are not military, in the same sense that the main roles of science and technology in a developed, industrialized and competitive country are not military.

Geraldo L. Cavagnari.

Research programs in applied fields like electronics, new materials, biochemistry and others, should only be established in association with identified partners in industry, which should contribute with their own resources, and be involved from the beginning in the establishment of appropriate objectives; they should be subject to independent evaluations of economic, managerial and scientific feasibility, and monitored on these terms.

New actors should be brought in projects of local and regional development, including local and state governments, business associations, financial institutions, universities and technical schools.

Education

The main challenge for Brazilian science and technology in the coming years is to spread competence for innovation horizontally, to the productive system as a whole, and to increase the educational level of the population. While this

is not done, the S&T establishment is bound to relate only to a small part of the country and its economy, with limited resources and relevance.

Box 15

Human resources development in South Korea

South Korea developed a massive effort in the fields of education, Science and Technology since the sixties, as part of their strategy of industrial conversion. Besides the sheer size of the effort, there are some strategies worth stressing, regarding the bridges they sought to create between the worlds of education and research and the world of industrial production.

Long-term programs of institutional development.

Universities, individual professors and research centers received support for five to six years long projects, time deemed necessary for the creation of groups of graduate students.

Well-known scientists were dissuaded to lend their names just to fatten the curriculum of projects. Those who gave their names had to be involved. With this, it became easier for young scientists to take the leadership of important projects.

Scientists and engineers were sent systematically to short courses abroad, in selected fields. Typically, their courses lasted two months, but they received four months fellowships. During their courses, they had to negotiate with they professors for training internships in European firms, to absorb technology.

An excellent researcher had difficulties linking to the productive sector. He received a grant to organize monthly lunches with business leaders, to discuss questions related to the interaction between basic science and applied technology.

C. M. Castro and J. B. Oliveira.

Policies for science and technology should not wait for educational reform, but they cannot be expected to succeed without profound transformations in the educational system as a whole, through increased access to educational opportunities, quality improvement of basic and secondary education, strengthening of technical education and diversification and better use of public resources in higher education. Questions of educational policy lie beyond the scope of this document. However, a few items should be stressed regarding the interfaces between the educational and the S&T sectors:

Technical education. Brazil has maintained a wide gulf between education for the academic professions, including engineering, and middle-level professional training, the first provided by universities, the second by federal and state technical

schools (and also by industry and commerce through their own institutions, Senai and Senac). The knowledge-intensive basis of modern industry and services requires the development of general skills for the technician, and proximity with industry for the institutions trying to provide technical education through formal course programs (box 15). Brazil has lagged behind the worldwide trend of developing post-secondary, short-term course programs as alternatives to conventional university education. The expansion of post secondary, technical education, developed with close links to industry, should become a central task for public universities and state governments. Although more difficult at the beginning, this new emphasis could prove more useful than the sheer expansion of evening course programs that became mandatory for public universities in the recent past; and more realistic, in budgetary terms, than the proposed multiplication of federal technical schools operated by the Ministry of Education.

Extension work and continuous education. University research departments and institutes should be stimulated to become more intensely involved with extension work and continuous education. An important activity in this regard is the systematic translation into Portuguese or rewriting of science education textbooks and engineering documents (handbooks, standards, technical manuals for craft and skilled workers) needed for general use in industry and education. These activities already take place in some universities, but are usually considered of low prestige, and inimical to academic excellence. It does not have to be so. High quality research centers can attract more resources, increase their relevance and involve more people through extension activities. Institutions with little to offer in terms of research can gather strength and recognition, and provide their students with significant opportunities for practical training. Since most of these activities can be paid for by users, they do not require much in additional resources, but there should be means to provide rewards, incentives and recognition for this type of work.

Teaching of science and technology. Academic departments in universities should take more responsibility for undergraduate education. The current departmental structure tends to leave undergraduate career programs without intellectual leadership, and undergraduate teaching is often seen as a burden by professors engaged in graduate education and research. Incentives should be created to stimulate researchers to get involved with undergraduate education, by writing textbooks, bringing undergraduates to their research projects, and participating in the upgrading of their course programs. Fellowships for undergraduates ("bolsas de iniciação científica") should be expanded, and successful involvement in undergraduate education should be added as a criterion for Capes in its evaluation of graduate programs.

General education. Most undergraduate education in Brazil, as elsewhere, is in fields like administration, languages, social sciences and the humanities. They

can be considered "general education" course programs, since they have little knowledge specificity, and are supposed to provide the students a broad spectrum of cultural, social and historical disciplines. There is a tendency to see these "soft" fields as a waste of time and resources, under the assumption that they are not directly relevant to the production of goods. However, general skills, social and cultural abilities are central components of modern economies and societies, characterized by intense flows of information and communication, the continuous expansion of services and a shifting social and economic environment. The situation of neglect should be reversed, with the graduate and research sector taking responsibility for improving the quality of secondary and undergraduate general education, through direct involvement in the production of good quality textbooks, the development of curricula and new teaching methods. Here again, adequate procedures should be devised to make these activities more rewarding and prestigious than they have been so far.

Distance learning. Modern technologies for distance learning have not been adopted in Brazil except in some isolated experiences in basic education. A systematic effort should be made to incorporate the international experience, and a few universities should be stimulated to begin pilot projects using the newly available instruments, from computers to electronic mail.

Infrastructure for information and knowledge dissemination

New and systematic procedures to incorporate technology into the industrial process should be developed, with strong emphasis on the development and dissemination of norms and standards, information, and procedures for technological transfer and quality improvement. Brazil has several institutions created for these tasks, such as the National Institute of Metrology, the National Institute of Intellectual Property and the Brazilian Institute for Scientific and Technological Information (Ibict). These institutions, however, have lived in a no-man's-land between the researcher in academic institutions and the productive sector, both of which were either protected from external competition, or linked directly to their own sources of information and technology outside the country. Without closer interaction with the users of their services, these institutions tended to become rigid and bureaucratic, weakening still further their links with the scientific and productive sectors.

To reduce this problem, users should play a much stronger role in the definition of the goals and practices of these institutions. A well organized and properly funded knowledge infrastructure is necessary to assure the easy access of scientists to libraries and data collections in the country and abroad. Significant advances have occurred in the last few years, through the gradual generalization of access to Internet and similar networks for Brazilian univer-

sities and research groups, and the development of computerized library catalogs in some of the main universities. Now it is necessary to make these links more widely used, more effective and more transparent to the individual researcher, and to establish means to bring the documents and data to the scientist's working place. A coherent policy for creating, maintaining and expanding these information resources is needed, and should rely on the competence developed by Fapesp, the National Laboratory of Computer Science Research (LNCC), the Institute of Applied and Pure Mathematics (Impa), and other groups that have built and developed the current facilities.

Institutional reform

For these policies to be carried on, governmental agencies for S&T policy should become smaller, more flexible and more efficient. The Brazilian agencies for science and technology are considered more efficient, and less plagued with problems of political patronage and bureaucratic formalism, than most of Brazil's civil service. However, with a few exceptions, the general evaluation of the main government agencies is not very positive. CNPq has grown to be a large bureaucracy, going from 1,502 employees in 1988 to 2,527 in 1992, about half of them without a university degree (Barbieri; table 2). Its administrative expenditures have varied enormously throughout the years, and most of its resources are now given to fellowships. Researchers and fellows applying for its resources complain constantly about the difficulties in getting information and receiving their fellowships and grant money on time. The agency could never establish a competent information system about its own activities, and there is little or no follow-up of the results of its investments in research and graduate education. Finep also increased its bureaucracy to about 700 employees, while its resources shrank (Frischtak, 1993). There are no established dates for submission of projects and proposals nor public announcement of awards. Without systematic peer review, there is no information on how decisions are made. In both cases, the problems were compounded by budgetary uncertainties. The agencies do not know how much money they will have at any given time, and their decisions are often based on expectations that are not fulfilled. Finally, these agencies have not established adequate procedures to receive proposals in constant values and protect their grants from inflation. The consequence is that, when a project is finally approved, its value is significantly lower than when it was presented, and still lower when the money is received and spent.

Table 3
CNPq — Budget according to main lines of activity, 1980-92
US\$ millions of 1992^a

Year	Fellowships	Grants ^b	Institutes	Administration	Other ^c	Total
1980	42,252.3	23,166.3	26,233.9	40,598.9	4,243.2	136,494.6
1981	46,567.7	21,815.5	29,557.7	41,837.5	2,420.1	142,198.5
1982	72,396.3	37,793.5	34,489.4	35,032.4	2,265.8	181,977.4
1983	68,137.6	28,106.6	26,949.6	28,769.8	3,194.6	155,158.2
1984	61,400.8	21,521.1	23,092.8	37,682.4	5,034.5	148,731.6
1985	88,153.1	41,517.0	33,141.5	33,631.7	5,212.8	201,656.1
1986	94,630.1	50,996.2	35,497.9	27,931.3	7,552.3	216,607.8
1987	184,069.4	48,886.4	57,739.4	63,729.7	4,416.3	358,841.2
1988	238,004.4	46,552.1	49,322.2	47,281.9	4,415.3	385,575.9
1989	236,143.1	33,570.1	85,569.2	48,693.0	22,732.4	426,707.8
1990	178,339.5	41,672.8	50,529.1	36,513.3	14,684.5	321,739.2
1991	232,440.4	19,884.0	30,838.3	26,361.2	14,907.9	324,431.8
1992	193,820.4	7,635.8	30,655.5	17,362.2	10,603.2	260,077.1

^a Compensated for inflation according to the General Price Index of Fundação Getúlio Vargas, and converted to dollar according to the mean exchange rates of 1992.

^b Includes special projects.

^c Includes debt service payments, fringe benefits to employees (for food, nursery, and transportation), persons working for other government agencies.

Source: CNPq, *Informe Estatístico*, Brasília, 4(2):13, abr. 1993.

In contrast, Fapesp, in the state of São Paulo, and Capes, at the Ministry of Education, are perceived as success cases. Fapesp works almost exclusively through peer review, its administration is very small, communication with applicants is very efficient, its grants are fully corrected for inflation, and has well-designed follow-up procedures for its grants and fellowships (box 16). Capes suffers some of the difficulties of being within the Ministry of Education, but has an established tradition of peer review assessments. Its leadership has been always recruited among persons of good academic standing, and its bureaucracy remains small.

Box 16
The Fapesp model

The Fapesp model is characterized by three main aspects. First is the source of its resources. Initially, Fapesp was granted 0.5 per cent of São Paulo's state revenues. The 1969 state Constitution increased this legal percentage to 1 per cent, less 25 per cent of the trade tax (imposto de circulação de mercadorias) which is transferred by the state to the municipalities; and it determined that the resources should be calculated each month, and transferred in the following month. To this basic source one should add the revenues of Fapesp's capital investments, which allows the agency to spend more than what it gets from the government in a given period.

The second aspect is related to its relative independence from political fluctuations. Fapesp is governed by a council of 12 members with fixed six year mandates, which is responsible for its administrative, scientific and patrimonial policies. Six members are designated by the state governor, and the other six are also chosen by the governor from lists submitted by the state's public universities and research institutes. The president and vice-president of the council are also appointed by the governor. In practice, all names are suggested to the governor by the scientific community.

The third aspect is that most of the resources go to individual researchers working in the state of São Paulo, and only rarely to institutions. Proposals are submitted to Fapesp and evaluated by peers. Their identities are not known to the applicant, and their recommendations are almost always followed by Fapesp. The reviewers are requested to follow up the projects, and can recommend the interruption of support.

Most Fapesp resources go to fellowships and individual grants, but in 1993 there were 56 institutional projects with total budget of US\$4.5 million, plus 119 fellowships linked to these projects. Besides, there were 94 "special projects" between 1963 and 1989. In 1990 they were replaced by team or thematic projects, 87 of which were approved by the end of 1991.

Milton Campanário and Neusa Serra.

These experiences provide a basis for the following suggestions for institutional reform:

— The Ministry of Science and Technology should restrict its role to matters of policy, financing, assessment and evaluation, without carrying on R&D activities under its direct administration. Although a science adviser or an equivalent cabinet-level position for science and technology is clearly necessary, the very existence of a formal ministry of science and technology, with all its overhead costs and exposure to political patronage, should be reexamined.

— The existing system of federal institutions for scientific and technological support should be evaluated in terms of its ability to perform the functions needed by the sector: support for basic research, support for applied projects, large and small research grants, fellowship and training programs, scientific information, norms and standards, and others. Brazil needs a federal agency to provide long term, sizeable grants for institutions and cooperative projects. This was the role played in the past by the National Fund for Scientific and Technological Development (FNDCT), administered by Finep. Whether these resources should be managed by Finep, CNPq or by a new institution should be examined as part of a broad review of the roles, jurisdiction and competencies of the existing agencies.

— Financing agencies should be organized as independent, state owned corporations, and free of formalistic and bureaucratic constraints. They should be placed under strict limitations regarding the percentage of their resources they can spend on administration, and should be supervised by high-level councils with the participation of scientists, educators, entrepreneurs and government officers. They should rely on external advice for their decisions, and their bureaucracy should be limited to the minimum.

— Research institutions and public universities should not be run as sections of the civil service. They need to have the flexibility to set priorities, seek resources from different public and private agencies, and establish their own personnel policies. While this is not changed, there is always the alternative of developing hybrid institutions with flexible mechanisms coexisting with more rigid procedures (the Brazilian academic community has some experience in this). Universities should develop appropriate settings for interdisciplinary work in new fields such as biotechnology and artificial intelligence (Carvalho; Silva).

— No research institution receiving public support, and no government program providing grants, fellowships, institutional support or other resources to the S&T sector, should be exempt from clear and well-defined procedures of peer evaluation, combined, when necessary, with other types of economic and strategic assessments. Peer review procedures should be strengthened by the federal government, made free from pressures of regional, professional and institutional interest groups, and acquire a strong international dimension. For instance, research proposals could be easily distributed to international referees through electronic mail.

— It should be the task of the Ministry of Science and Technology to stimulate such reforms in other branches of the federal government. The Ministry of Education should have a particularly important role in maintaining the quality and the autonomy of the research groups in the federal universities.

— It should be also the task of the Ministry of Science and Technology, in cooperation with the Ministries of Finance and Foreign Affairs, to keep the channels open for international cooperation between Brazil, international agencies and institutions, and the international scientific community. The World Bank, the International Development Bank and the United Nations Development Program have played important roles in providing resources for capital investment, research support and institutional development of Brazilian institutions. This presence should be maintained not only because of the resources involved, but because of what they bring in terms of international perspectives and competence. In the future, such agencies could be very helpful in a process of institutional reform. As a rule, cooperation among scientists, research institutions and private foundations in different countries is established directly, and need the support, but not the interference, of governmental agencies.

Goal-oriented projects

The broad changes suggested in this document do not preclude the adoption of well-identified projects linking science, technology and the productive sector, aimed at the strengthening of specific fields and orientations in the natural and social sciences, the establishment of instruments for S&T diffusion and education, and others. Proposals of this kind are present in the background studies commissioned for this study, and will emerge as a matter of course whenever decisions have to be made about the allocation of scarce resources, the beginning of new lines of work, and the phasing out of others. It is necessary to develop a list of main areas of established competence and social relevance to be the focus of future investments; to identify areas that should be phased out, or reduced; and special weaknesses and competencies in need of strengthening and support. Two very broad principles should preside this policy-making process:

It would be inappropriate to assume that science and technology would develop and increase its usefulness in a peripheral region if left alone to respond to market mechanisms of economic and scientific competition. The distribution of science and technology, as it is well known, is very lopsided in any given field and region, and the current expansion of communications and trade is leading to further concentration of knowledge, competence and technical resources. Policies are needed for general and technical education, for bringing flexibility and introducing accountability in public-supported institutions of higher education, research and development, and for introducing standards of quality. The trend toward concentration cannot be stopped by policies of isolation and self-sufficiency, or subsidies to second-class institutions and research groups. But it is not a zero-sum situation. As the world gets more integrated, information circulates, and the knowledge basis increases, there are new opportunities to be grasped. For this, they have to be properly perceived and understood, and adequate investments in education should exist.

Box 17

A goal-oriented project: strategic development of computer science

The strategic development of computer science project (Desi) is supported by the National Research Council, through its division of special projects, and the United Nations Development Program. It combines research projects proposed by members of the scientific community with a broad project aimed to develop a national software industry for export and a national infrastructure for communication and computer applications.

The project is divided in three programs, the National Research Network (RNP), the multi-institutional thematic program (Protem) and the software program (Softex). RNP is a computational infrastructure aimed to create a network linking all scientific and research institutions in Brazil with each other and with the rest of the world. Proteem was initiated by the National Research Council's advisory committee in computer science to create, for their field, a mechanism similar to those created by PADCT for other high technology fields. CNPq provided an initial grant which led the main research centers in computer science to associate around subjects deemed strategic, generating more than 100 cooperative projects. If carried on as planned, Proteem is expected to generate a quality jump in this field of research. Softex was created under the assumption that Brazil could become a significant exporter of software to the international market. It is supposed to provide assistance to software producers on how to gain competitiveness in the international market, and to establish a network of supporting groups to provide industries with advanced development technologies, and to link them with universities and research institutes.

The Desi project has an estimated budget of US\$27 million for three years. The expectation is that 13 groups for cooperation between industry and research institutions could be established in the most research and industrially intensive regions in the country.

Extracted from Carlos J. P. Lucena.

Brazil has had some experience of integrated programs covering specific areas of interest, such as tropical diseases, natural resources, energy and computer sciences. PADCT has followed a similar pattern, by choosing a few, selected areas for support, and assigning a given fraction of its resources to them. An integrated program would have, ideally, resources for combined activities of basic and applied research, graduate education and training. For the fields chosen for such programs, the benefits seem obvious, since their resources are guaranteed, and the links between basic and applied research and education can be made more coherent (box 17). There are, however, three pitfalls for such programs, which should be avoided. First, they run the risk of isolation. As with any applied

project, integrated programs need to have clearly identified and active partners outside the research and education sector — be they the health ministry, the electronics industry or public utility companies. In fields that are economically relevant, they should be linked to specific industrial policies, with the participation of relevant business leaders. When this pattern is not present, the results of the integrated project are not used, and the effort can be wasted. Second, there is always the temptation to distribute the R&D resources arbitrarily among programs, creating unwarranted imbalances. Third, self-contained programs are prone to shun peer review evaluations and give excessive protection to a few institutions and research groups, disregarding excellence in favor of selected subjects or problems. If these difficulties are considered if there are clearly identifiable partners in government and industry, if there are no arbitrary block assignments of resources, and if peer review procedures are kept in place integrated programs can be important and forceful instruments for improving the country's S&T capabilities.

6. Conclusion

The plurality and complexity of modern science and technology require the research institutions in universities, government and even the private sector to engage in a plurality of activities, from basic to applied science, from graduate education to extension work and teacher training. They should be also stimulated to diversify their sources of money, from government to private companies, non-profit foundations and paying clients and students. Specialization will take place, if necessary, and should grow through a combination of external incentives and internal drive. Scientific research and development, to remain alive, should take place in a highly internationalized and competitive environment for resources, prestige and recognition; and the leading scientists should be also entrepreneurs of this knowledge enterprise.

Papers commissioned for this study

(a) general papers:

Branscomb, L. U.S. science and technology policy: issues for the 1990s. Lewis M. Branscomb, director, Science, Technology and Public Policy, Center for Science and International Affairs, Harvard University.

Brisolla, S. Indicadores quantitativos de ciência e tecnologia no Brasil. Sandra Brisolla, Núcleo de Política Científica e Tecnológica, Universidade Estadual de Campinas, São Paulo.

Castro, C. M. & Oliveira, J. B. Os recursos humanos para a ciência e tecnologia. Cláudio de Moura Castro e João Batista Araujo e Oliveira, International Labor Organization (presently at the World Bank).

Ferné, G. Science & technology in the new world order. Georges Ferné, Organization of Economic Cooperation and Development, Paris.

Guimarães, E. A. A política científica e tecnológica e as necessidades do setor produtivo. Eduardo Augusto Guimarães, Instituto de Economia Industrial, Universidade Federal do Rio de Janeiro.

Schott, T. Performance, specialization and international integration of science in Brazil: changes and comparisons with other Latin American countries and Israel. Thomas Schott, Department of Sociology, University of Pittsburgh.

Skolnikoff, E. U.S. science and technology policy: the effects of a changing international environment. Eugene B. Skolnikoff, Massachusetts Institute of Technology, Boston.

(b) basic and applied sciences:

Azevedo, J. A pesquisa agropecuária no Brasil. João Lúcio Azevedo, Escola de Agricultura Luiz de Queiroz, Universidade de São Paulo.

Carneiro Júnior, S. O estado atual e potencialidades do ensino de pós-graduação e da pesquisa em engenharia no Brasil. Sandoval Carneiro Júnior, Coordenação dos Programas de Pós-Graduação em Engenharia (Coppe), Universidade Federal do Rio de Janeiro.

Carvalho, A. Biotecnologia, Antonio Paes de Carvalho, Instituto de Biofísica da Universidade Federal do Rio de Janeiro and Fundação Bio-Rio.

Cavagnari, G. P&D militar: situação, avaliação e perspectivas. Geraldo L. Cavagnari, Núcleo de Estudos Estratégicos, Universidade Estadual de Campinas.

Cordani, U. Geociências. Umberto Cordani, Instituto de Geociências, Universidade de São Paulo.

Dietrich, S. Botânica, genética e zoologia. Sonia M. C. Dietrich, Instituto de Botânica, Secretaria do Meio Ambiente do Estado de São Paulo.

Lucena, C. A situação atual e o potencial da área de computação no Brasil. Carlos J. P. de Lucena, Departamento de Informática, Pontifícia Universidade Católica do Rio de Janeiro.

Paiva, A. Physiological sciences. Antonio C. M. Paiva, Instituto de Biofísica, Escola Paulista de Medicina.

Ramos, O. L. REA da saúde. Oswaldo Luiz Ramos, Escola Paulista de Medicina.

Reis, F. A avaliação das ciências sociais. Fábio Wanderley Reis, Universidade Federal de Minas Gerais.

Resende, S. Avaliação da REA e proposições para a física no Brasil. Sérgio Resende, Departamento de Física, Universidade Federal de Pernambuco.

Riveros, J. Uma visão atual da química no Brasil. José M. Riveros, Universidade de São Paulo

Silva, W. S. A pesquisa em inteligência artificial, seus antecedentes intelectuais e suas características locais. Walzi Sampaio da Silva, Universidade Federal Fluminense.

(c) technology and industry:

Castro, N. A. 1993. Impactos sociais das mudanças tecnológicas: organização industrial e mercado de trabalho. Nadya Araujo Castro, Universidade Federal da Bahia e Cebrap.

Goldemberg, J. Tecnologia, política energética e meio ambiente. José Goldemberg, Universidade de São Paulo.

Kupfer, D. Política de qualidade no início da década de 90. David Kupfer, Instituto de Economia Industrial, Universidade Federal do Rio de Janeiro.

Pereira, L. Sistema de propriedade industrial no contexto internacional. Lia Valls Pereira, Universidade do Estado do Rio de Janeiro.

Tigre, P. Liberalização e capacitação tecnológica: o caso da informática pós-reserva de mercado no Brasil. Paulo Bastos Tigre, Instituto de Economia Industrial, Universidade Federal do Rio de Janeiro.

Verulm, R. O setor de bens de capital no Brasil. Roberto Verulm, Faculdade de Economia e Administração, Universidade de São Paulo.

(d) institutional aspects:

Barbieri, J. Conselho Nacional de Desenvolvimento Científico e Tecnológico. José Carlos Barbieri, Fundação Getulio Vargas.

Campanário, J. & Serra, N. Sistema Estadual de Ciência e Tecnologia (São Paulo), Milton A. Campanário and Neusa Serra.

Erber, F. & Amaral, L. Os centros de pesquisa das empresas estatais: um estudo de três casos. Fábio S. Erber, BNDES and FEA/USP; and Leda U. Amaral, Eletrobrás.

Guimarães, R. FNDCT — uma nova missão. Reinaldo Guimarães, Universidade do Estado do Rio de Janeiro.

Stemmer, C. Programa de Apoio ao Desenvolvimento Científico e Tecnológico — PADCT. Caspar Erich Stemmer, Universidade Federal de Santa Catarina.

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Comments on "Science and Technology in Brazil"

Michael Gibbons*

There is much good sense in the paper under discussion this morning. The problems facing Brazil today and how it got there are presented clearly and plausibly. In summary, the scientific, technological and educational developments established in the seventies have begun to stutter. According to the paper, the reason for this is primarily economic. Brazil has fallen on hard times; economic growth has collapsed with the recession, inflation rocketed, and as a consequence most of the major institutions associated with the development of a robust national scientific and technological capability — government research establishments and universities — are in difficulty. Original policies aimed to establish Brazil's scientific and technological capability no longer seem to be working. Links with industry are weak. Indeed industry seems to be a relatively poor performer of R&D. The thrust of the paper is to develop new policies which face squarely the economic realities of the nineties.

At the core of the paper are recommendations for a three-pronged S&T policy. The basic idea is to put Brazil's scientific and technological institutions back on an even keel by providing separate funding mechanisms for basic research, applied research/technology and education. The aim is to strengthen the universities as the prime providers of basic research and of highly qualified manpower while, at the same time, providing a separate flow of funds for the country's nest of research institutions — the so-called associated laboratory scheme. Difficulties noted include the growth of bureaucracy in the previous regime, the quality of the peer review system, and the reluctance of industry to support R&D out of its own funds.

All of this is plain good sense. But the three-pronged policy aimed at revitalising the scientific and technological institutions of the country has a degree of distinctness that carries the danger of a separation amongst knowledge producing institutions which need to be highly interactive. One consequence of this might be to encourage the persistence of an essentially science-push model of economic regeneration. This, at precisely the time when linear models of innovation have been discredited and when the production of scientific and technological knowledge has become increasingly inter-connected and global. To be sure the policy paper does not recommend institutional separation. Indeed it recognises that pure and applied science now overlap. This is acknowledged in the paper: "The fact

* Director, Science Policy Research Unit, University of Sussex.

that the basic science, applied R&D and high level technical education are very often indistinguishable, and take place simultaneously in the same institutions, does not mean that they should not be treated separately in terms of their supporting mechanisms, working from different perspectives and with different approaches". True enough but funding mechanisms have a way of acquiring a life of their own and constant vigilance will be required if the conditions which prevail in the production of science and technology are not explicitly recognised.

The key insight is that S&T policy must be related to industrial policy. In fact, what is needed in Brazil is a national innovation policy because the notion of innovation carries with it the idea that a set of relationships are involved and that they must function over an extended time period; innovation policy is an integrationist policy. The premise of this policy should be to get industry moving and moving under its own steam. To do this the appropriate S&T policies should be functionally related to the level of competence of each particular sector. No country, even the wealthiest, can any longer afford to support a comprehensive S&T base in the hope that economic growth will somehow follow. By contrast, around the world science policies are now conceived in relation to technology and industrial policy. This aspect of S&T policy seems to me undeveloped in the paper under discussion. Following Krugman, and eschewing the current hype around competitiveness, national innovation policy should be guided by the assumption that "the coming struggle in which each big economy will succeed or fail [will be] based on its own efforts, pretty much independently of how well the others do" (Krugman, 1994). If he is right, then the basis of the future independence must lie with the performance of the country's wealth creating institutions. If they are working correctly, the rest will follow. The danger in the current formulation is that a fresh attempt will be made to strengthen the knowledge producing institutions independently of the wealth creating ones.

The idea of orienting S&T policy closely with industry is not a popular one. Scientists, in particular, are always quick to point out the dangers that will arise in terms of future discoveries and manpower provision if the scientific enterprise is not supported vigorously. But there will be no support at all for science if national firms cannot generate wealth in the first place. And overwhelmingly, wealth is generated by applying existing knowledge, not by generating new knowledge (Branscomb, 1993).

This is true in all sectors of manufacturing industry at all times. What differs is the types of knowledge needed. Clearly there are differences in the knowledge requirements of a world class pharmaceutical firm and a mechanical engineering firm operating in a remote corner of a developing economy. But there can be no argument that, in both cases, knowledge is necessary and if it is to be utilized it must be assimilated and develop largely inside in the company itself.

Brazilian S&T policy needs to be sensitive to the different knowledge requirements of its particular sectors. In relatively few of these will the company be operating at the frontier of world class innovation. The question is, given that

the firms in a particular sector are likely to be relatively laggard, how is it possible to move from that position closer to the market leaders? How can they begin from where they are in terms of technological competence into a position where latest science and technology can be appropriated? In this, what is usually termed R&D should come towards the end of a rather long and multistage process — as a result of previous industrial innovation — not at the beginning, as the engine on which all expectations are concentrated. We need policies to support some kind of "reverse linear model".

Some experience of other countries

We can begin from experience in the United States. Here there has been a good deal of soul searching over the policies of the large national companies who in the sixties began siting their manufacturing operations offshore — in low wage economies. It now appears that the firms in some of these countries are now able to compete very effectively with the United States in precisely those markets where initially foreign direct investment (FDI) was placed. To sum up a rather complex set of histories, in the transfer to low wage economies, the Americans have "lost control over what they used to make". How can this be? How can a relatively backward economy — at least in terms of technology and skills — acquire the knowledge and skills to effectively displace the parent company? Americans are worried about this loss of control over what they used to make. Many examples are given in an MIT study entitled *Made in America* (1989) and in *Manufacture Matters* (Cohen & Zysman, 1987). The point of introducing this work here is simply to point out that it seems to be possible for some firms to begin in the middle of the innovation cycle with the mature technologies of an established design configuration, and with a relatively low level of technical and marketing competence move on to become one of the leading players.

Another example, this time from the United Kingdom. During the seventies the motor vehicle and television tube production by United Kingdom firms virtually ceased. Twenty years later Britain is a world leader in the manufacture and export of both cars and TV tubes. Manufacturing is not, in the main, carried out by British firms but by Japanese ones who have invested in Britain. How was this accomplished? In a recent paper, D. Eltis has used these two examples for the purpose of showing that FDI can have beneficial effects in a sector that has lost the technology and skills to compete internationally in the manufacture of complex products. The Japanese firms did not begin by carrying out R&D in Britain. Rather, they established the most sophisticated plant, hired British workers, and trained them in its use. The effect of a high technology plant in its midst has, among other things, the effect of forcing suppliers to innovate and of building up local cultures of excellence related to the main products — in this case motor cars and television tubes. Although evaluating the benefit of such FDI is a com-

plex matter, it would be interesting to explore the full effects of these investments on the local culture of innovation.

The experience of the East Asian Dragons provides a range of dramatic examples of innovation in the electronics sector where companies were able to join in the middle of the game, as it were. In some of these FDI was important, in others it wasn't. Although foreign investment is dealt with most extensively in the literature on technology transfer, historically FDI has contributed with only relatively little of the capital formation in the Dragons. The two largest economies, Korea and Taiwan, have been fairly closed to FDI, with governments exercising strict control. FDI contributed around 2 per cent to Korea's total capital formation during the period of 1976 to 1987 (James). In the case of Taiwan, between 1965 and 1985, FDI oscillated between 1.35 per cent and 4.32 per cent of total capital formation and between 2.5 per cent and 5.47 per cent of total private capital formation per annum (Dahlman & Sananikone, 1990). In contrast, FDI contributed around 18 per cent to Hong Kong's total capital formation during the period (Hobday, 1991). In the case of the Dragons, what happened, if not FDI? The short answer is that the economic transformation of those economies rests upon a whole range of measures which encourage market growth and technology assimilation. The principal mechanisms are: joint ventures, licensing, imitation, sub-contracting original equipment manufacturer (OEM), company acquisitions and strategic partnerships. Of these the most important, particularly in the early stages of industrialization, appear to be OEM agreements.

A definition of OEM

Original equipment manufacturer (OEM) is a specific form of sub-contract. Like a joint venture it requires close connection with the foreign partner. Under OEM deals, the local firm produces a good to the exact specification of the foreign company. The foreign firm then markets the product through its own distribution channels, under its own brand name. OEM often involves the foreign partner in the selection of equipment, training of managers, engineers, and workers. It is to be contrasted with own design and manufacture (ODM), where the local firm designs the product to be sold by the TNC.

What are the common factors in these very diverse experiences? I believe a key factor is that through these various mechanisms firms acquire and assimilate knowledge; that is, they learn. A second factor is that learning must begin from where the firms are, with the resources that are available. Although the level may be low to begin with, it doesn't need to stay there and, in the case of the East Asian Dragons, it certainly didn't. Thirdly, the learning took place locally and cumulatively. Fourthly, the locus of action is the national corps of entrepreneurs and managers.

The centrality of learning is important. We know that much technology transfer can lead to disappointing results, often because the local learning capability is lacking. More positively, from the point of view of Brazil, we know from a number of American studies that United States firms gave away important informational knowledge by underestimating the power of local learning capability (Cohen & Zysman, 1987). It might be useful just to remind ourselves that the learning in question is particular to specific markets and if the focus was more on the product — what is learned — than the process — learning — then we would be talking about technology and its acquisition. I hope that is clear.

Studies of learning attempt to show how technological know-how is acquired within firms and related institutions. Learning refers to the mechanisms by which firms generate capabilities in products, processes and related organizational structures. Learning is largely embodied in the skills of the workforce and managers. Malerba (1992) demonstrates the importance of learning to firm-level incremental technical change, productivity change and to different types of product and process improvement. Learning normally involves substantial and deliberate effort and investment on the part of the firm. Developing country research has shown that learning is important to technological and institutional progress (Fransman & King, 1984). Dahlman et al. (1985) show that learning develops in sequence, shifting from production to investment to innovation capabilities. Similarly, Lall (1982) discusses the passage from elementary to intermediate advanced learning. Lall also shows how non-technological learning is important to organizational development (e.g. marketing and managerial skills).

However, few of these studies of developing countries relate technological learning to export marketing channels. Nor do they examine firm strategies towards learning, preferring instead to describe general characteristics of learning at the industrial level. As a "first approximation" of how the process of technology assimilation links to marketing development, the model (developed below) may provide a useful framework.

The question is: if the game of international competitiveness has a technological dimension, how do latecomers join? Can they start towards the end of the product cycle and hope to move to a position of dominance at some later time? It is a chronic problem. Do the innovators always have to be in the lead, and are the followers always laggard? The clear answer is, No! Whatever else it may be, international competitiveness is a complex game, but, equally, it is unrealistic to expect to be able to jump into the lead in a particular sector without the proper preparation. No policy is likely to be very effective if it neglects the fact that technological innovation is not a once off accomplishment, but an unending process aimed at adjusting technological capability to continuously shifting market needs. The path to economic prosperity is dynamic and path dependent. This means that learning — technology acquisition — must be continuous and incremental, and firms have no other option but to begin from where they are. For some governments, this is a hard lesson to learn.

In the next section, a simple model is presented, based on some recent work of Hobday and others. The model is based on the by now clearly established fact that successful innovation is characterized by a close and continuous connection between technology development and the market. The premise, therefore, is that for latecomer firms the problem is to find a way to join an on-going process of technology-market interactions. The challenge is to do this beginning with relatively low level technical resources and with very weak market information. Current innovation theories would suggest that the key to this process for firms to get in early on a new innovation/product cycle and through learning move from these uncertain beginnings to capture economic benefits which will only emerge as product and process technologies mature. Many contemporary S&T policies accept this view. Hence the interest in generic technologies and large demonstrator projects. Such policies are R&D driven. They are intended to set the stage for firms to get in early in the next innovation cycle, but would seem to exclude latecomer firms precisely because they would lack the knowledge and skill to assimilate the knowledge produced in these R&D driven projects. In the model developed below, it is proposed to show that latecomer firms can and often do start in the mature technology stage and move "backwards" to the R&D and design stage.

Export-led technology development — a simple model for latecomer firms

A latecomer firm is defined as one located in a developing country, outside the locus of world innovation and R&D. Such a firm does not face demanding buyers in its domestic markets which, as Porter (1990) shows, is often a key factor in competitive performance. Similarly, the latecomer firm is cut off from leading industrial clusters and important marketing networks. The firm typically suffers from lack of related support industries and a poorly developed technological infrastructure. To prosper, the latecomer must overcome these difficulties (Hobday, 1991).

Market development

The left hand column of the table summarizes a five stage technology-marketing model which is based upon learning as the prime mode of technology assimilation (see notes). Regarding both marketing and technology, the model does not assume any rigid or automatic stages of development. Progress depends primarily on the efforts of local firms and the opportunities afforded by foreign buyers. Some of the stages may occur concurrently as in complex innovation models and there may be feedback loops between earlier and later stages. External factors (e.g. policy actions and the state of the macro-economy) will impinge directly on the process. Many of the normal criticisms of innovation models apply to this scheme (Forrest, 1991).

The latecomer firm progressively internalizes the marketing skills and functions initially carried out by the foreign buyer or manufacturer.

— In the first stage the latecomer is entirely dependent upon buyers for product design skills, marketing, distribution and quality control. The local firm simply sells low cost production capacity.

— During stages 2 to 5 the latecomer firm assimilates more and more complex marketing functions. Spurred on by the prospect of growth and higher value-added activities, the firm learns how to conduct its own sales and marketing.

— It progressively broadens its range of customers and improves the packaging and quality of its products.

— By stage 5 the latecomer firm will have developed its own brand design which it will sell directly to customers overseas: it is no longer dependent on the distribution channels of foreign buyers and manufacturers. By this stage the latecomer will be indistinguishable from the leading firms in the West and Japan (see notes).

Technological assimilation

The right hand column of the table adds a technology dimension to the marketing model to suggest how successful latecomer firms gradually learn the techniques of manufacturing. (The technology scheme is based on interviews carried out during 1992 and 1993 with firms in each of the four Dragons, and a body of research into technological learning and developing countries.)

— In stage 1, it is likely that early NIC entrants begin with simple assembly skills and later assimilate incremental process capabilities. As their capacity expands and numbers of customers increase, they will need to learn how to control the quality and speed of production. During the early stages, firms are likely to remain dependent on outside sources of technology. However, technicians will begin to internalize key production skills.

— During stages 2 and 3, the latecomer firm will gain more and more control over its production process, spurred on by export market opportunities. By acquiring product and process capabilities it will be able to sell more higher quality products to a larger base of customers, bringing the advantages of low cost engineering and management to the market.

— The latecomer entrepreneur recognises that unless the firm goes through a series of difficult technology learning transitions it will remain “trapped” in the capacity export stage.

— By stage 4, the firm will embody sufficient skills to develop new products and processes. The latecomer will have surmounted its technological dependency in terms of product design, quality control and process engineering. It may have already forged links with capital goods suppliers and may conduct R&D into new products and processes.

— In stage 5, the NIC firm will have developed advanced skills and R&D capabilities. Technologically it will be indistinguishable from world market leaders. It will have successfully progressed to the higher stages of product and process development and will compete head on with the world leaders.

According to the simple model, early latecomer firms enter at the mature, standardized end of the product life cycle and cumulatively assimilate technology by internal learning. With each wave of new innovations that catch up little by little, closing the technology gap between themselves and the market leaders. They therefore travel backwards along the technology life cycle, reversing the “traditional” path of technology development, shifting from mature to earlier stages. In doing so, latecomer firms are able to gradually overcome their distance from the world technology frontier and compensate for the lack of demanding local users and consumers. Not all firms go through all stages. As the quality of the local infrastructure improves, new entrants are able to jump in at the later stages, responding to factor costs, market developments and the availability of skilled engineers and managers.

There may not always be systematic, causal links between the stages of technology and market development. It is theoretically possible for a firm to acquire advanced technological skills but to still remain at the early stage of marketing — or vice versa. However, manufacturing firms in the NICs tend to improve both their technology and marketing capabilities simultaneously. Marketing skills are needed for firms to capture value added associated with packaging, distribution, brand awareness and after sales service. Often these activities are more lucrative than manufacturing. Marketing is also needed for firms to expand their range of customers and determine the direction of their future business. Similarly, technological know-how is needed to develop new products and improve the efficiency of production. Firms have an incentive to expand their value added opportunities, to manage and reduce their dependency on foreign sources and to respond to competition from other latecomers. These processes require the internal acquisition of a range of marketing and technological skills.

In some of the stages there may be a direct link between market and technology. For instance, to achieve the advanced stage of product marketing push, firms will need sufficient R&D capabilities to convert market signals into innovative

new products. Similarly, when shifting from stage 1 to stage 2, firms will need to internalize process skills to expand production capacity, shorten delivery times and improve product quality.

Most importantly, the technology and marketing channels are often one and the same. For instance, under sales and exporting arrangements such as OEM, joint ventures and licensing, latecomer firms are presented with a technology transfer mechanism. Under OEM arrangements, the foreign corporation not only buys finished goods for export, but it will often supply technical specifications, training and advice on production and management. TNCs are often willing to assist in local assimilative efforts under OEM because they depend on the quality, delivery and price of the final output. The market-technology channels established under OEM are often long term. They allow latecomer firms to overcome initial barriers to entry and they supply the vital market information needed for local firms to target investments in technology and skills.

To sum up, in the above scheme, exports “pull” forward the technology of latecomer firms. Through OEM and other channels, export demand acts as a focussing device for technological investments and forces the pace of progress. Local competition stimulates the process as export leaders are imitated by followers. And, as the following evidence shows, firms do not simply “keep up”, but actually “catch up” as time progresses (World Bank, 1993).

Application: the case of the East Asian Dragons

Historical data from each of the four Dragons lend some support to the simple export-led technology development model put forward above. The evidence also illustrates the importance of assimilative learning efforts on the part of latecomer firms in electronics. Indigenous firms engaged in rapid technological learning under OEM, sub-contracting and other arrangements. Export-led market growth was closely coupled with technology assimilation through foreign channels of technology transfer including FDI, joint ventures, foreign buyers, licensing and OEM arrangements. These concrete institutional mechanisms enabled local firms to couple export market growth with in-house technological learning.

Through FDI foreign manufacturers provided initial examples for local firms to imitate (e.g. Anam of Korea). TNCs helped start up the electronics industries in each of the four countries, providing a source of training for local technicians, engineers and managers. Joint ventures with TNC enabled some of the largest firms in Korea to enter the business, while OEM and ODM arrangements later enabled many latecomer firms to build technological capabilities and secure international market outlets.

The four Dragons exhibited a wide variety of policy approaches which resulted in significant differences in industrial structure, corporate strategy, firm ownership and methods of technology acquisition. Korea progressively reduced its reliance on FDI by internalizing capabilities within the three chaebols and by

entering long term OEM alliances with, mainly, Japanese TNCs. Conversely, Taiwan and Hong Kong relied on a multitude of small and medium domestic firms, showing that the disadvantages of small firm size can be overcome. Again in contrast, Singapore depended almost entirely on FDI for the development of its electronics exports and the assimilation of technology.

There were a number of common factors essential to successful electronics development in the four Dragons:

1. The macroeconomic context must produce long stability and confidence. The literature shows that sound monetary policies, high domestic savings and export-led industrial policies provide a stimulating economic context for industrial development in each of the four countries (World Bank, 1993). Of course, such factors cannot explain the diversity of strategies towards technological and industrial development evident in the four Dragons. The Schwartzman paper, however, clearly indicates damage that instability has and is producing throughout the institutional structure that supports S&T.

2. The existence of skilled local entrepreneurs was essential to industrial development in three of the four NICs. In the absence of such entrepreneurs, Singapore chose to rely on foreign TNCs. A high degree of domestic competition was apparent in each case, despite plurality in ownership and industrial structure.

3. A further success factor was each government's investment in basic education as well as craft, technical and vocational engineering courses directed towards the needs of industry. Furthermore, at the corporate level, the coupling of technological learning with export demands enabled latecomers in each economy to climb the technological ladder and to progressively reduce the technological gap between themselves and the international market leaders. Recently, as latecomer firms' capabilities have increased, technology partnerships with leading American and Japanese companies have provided a means for acquiring highly advanced electronics technologies. Some of the latecomers have purchased overseas high technology firms to acquire skills and to access distribution channels directly.

The simple model put forward provided a useful first approximation for understanding the dynamics of market and technology development in the Dragons. As well as highlighting the market-technology linkage, the model suggested that latecomer firms tended to start with simple assembly and manufacturing tasks and, once mastered, proceeded to more complex design and development work. The evidence confirmed the view that technological learning is a cumulative, incremental process. The model also drew attention to the contrast between latecomer firm strategies and those implied in conventional models of innovation. In contrast with "Western" innovation models, latecomer firms begin with mature, standard-

ized technologies and gradually work their way "backwards" along the product life cycle towards new designs, process development and research.

One question which deserves further investigation is whether or not latecomer firms "innovate" as they learn the technology of electronics. The evidence suggests that firms do innovate, but in ways constrained by their latecomer structures and status. Innovation appears to be incremental rather than radical, while the focus of innovation is process, rather than product (at least in the initial stages). This type of continuous improvement pattern may have helped narrow the technology gap between East Asian firms and the market leaders, enabling them to "catch up" rather than just "keep up". However, more in depth research is needed to establish the breadth and depth of innovation in the latecomer electronic firms.

Conclusions

Schwartzman describes the new realities facing Brazil under two main headings:

- (a) changes in the role of science and technology in the international scene; science, technology and industry more closely integrated;

- (b) changes in the nature and capabilities of the Brazilian State; hindered by the problem of institutional and financial stability.

New policies required

The new policy should implement tasks that are apparently contradictory; to stimulate freedom, initiative and creativity of the researcher, while establishing strong links between their work and the requirements of the economy, the educational system and of society as a whole; and to make Brazilian science and technology truly international, while strengthening the country's S&T capabilities. To achieve this, the individual researcher, and his research unit or laboratory, should be freed from bureaucratic and administrative constraints, and stimulated to look for the best alternatives, in the country and abroad, for the use and improvement of his competence. This requires, in turn, a competitive environment based on public incentives and private opportunities that rewards achievement, increases the costs of complacency and underachievement, and gears a substantial part of the R&D resources toward a few important and strategically selected goals.

More specifically, the new policy should include the following tasks:

- (a) increase links between science and the productive sector;

- (b) create two different markets, one for academic science, another for applied technology;

- (c) increase links between science, technology and education;
- (d) invest heavily in the development of innovative capabilities of the production system;
- (e) support a few integrated projects;
- (f) create conditions for Brazil's participation in international programmes;
- (g) increase institutional flexibility and accountability (through more exhaustive peer review).

How does the model adumbrated above relate to these new realities?

The "reverse-linear" model proposed above imposes the idea of integrationist policy — of what has been called innovation policy. The first thing that the model draws attention to is the need to develop innovation policy on a sectorial basis. It would be a useful preliminary exercise to try to place each sector at its appropriate stage in the model. This would provide guidance as to whether S&T policy in particular cases ought to place priority on developing the technical infrastructure or the R&D infrastructure. If we presume that all firms in whatever sector will, one way or another, be latecomer firms, it is extremely important to know how "late" a latecomer they are. If they are late developers then the development of the technical infrastructure must receive priority. The reverse-linearity suggests that the lower strata of the educational system must be the priority. They are essential to define which sector is to begin to play a part in the technology-market interactions which characterizes the innovation process.

The new ingredient that I would add to Schwartzman's considerations lies in the centrality of learning. This will affect policies which aim to promote links between science, technology and education. Increasing the links between science and the productive sector, must begin first at the technical level if the firms are in the first stages, and then move on to the provision of R&D and design support. The strengthening of the technical infrastructure must come first, instead of preconditions that require a very sophisticated higher education sector or capability in fundamental research.

By identifying where each sector is in the model, it becomes possible to specify which sets of firms need explicit R&D support and *a fortiori* which areas of scientific and technological research ought to be strengthened. If firms are in the first two stages they do not need R&D support. It is unlikely that they could appropriate it. Classifying firms in this way might also make it easier to identify the strategic links with the international scientific community which need to be developed and perhaps even suggest which particular demonstrator projects ought to be launched. In brief, using the staging approach increases the probability that policy will be appropriate to the need of particular firms.

The recommendation which gives me the most trouble is the idea of developing separate markets for science and technology. It is feasible, perhaps even desirable, if most of the latecomer firms are in the early stages of technology-market process. However, in all the advanced sectors, as Schwartzman acknowledges, science is produced in the context of application and so the two markets interpenetrate. In such sectors it would be regressive to try to keep separate what broader markets has already begun to integrate. For the rest, however, it may well be necessary to have "particularized" markets which in terms of institutions and reward systems reflect the characteristics of particular sectors.

The outcome of all these policies would be to produce distinctive scientific and technical competences in Brazil. It is in the nature of contemporary knowledge production that such competence is both highly specialized and local. It is the job of government to broker that expertise in the wider international community.

Table
Stages of marketing and technology assimilation

Marketing stages	Technology stages
1. Passive importer-pull Cheap labour assembly Dependent on buyers for distribution	Assembly skills, basic production capabilities Mature products
2. Active sales capacity Quality- and cost-based Foreign buyer dependent	Incremental process changes for quality and speed Reverse engineering of products
3. Advanced production sales Marketing department established Starts overseas marketing Markets own designs	Full production skills Process innovation Product design capability
4. Product marketing push Sells directly to retailers and distributors overseas Builds up product range Starts own brand	Begins R&D for products and processes Production innovation capabilities
5. Own brand push Markets directly to customers Independent distribution channels, direct advertising Strong market research	Competitive R&D capabilities R&D linked to market needs Advanced product/process innovation

Source: Hobday, 1991.

Notes

1. Building on the research of Hone, Wortzel and Wortzel (1988) put forward a simple marketing scheme to show how NIC exporters graduate from supplying labor intensive assembly services to exporting advanced goods into foreign markets. Their seminal study is based on interviews with locally owned firms in three Asian Dragons (Korea, Taiwan and Hong Kong) as well as Thai and the Philippines. Covering three export industries (consumer electronics, athletics footwear and clothing), it is one of the only studies which systematically analyses the importance of export marketing to firms' growth in East Asia. Wortzel and Wortzel were not concerned with the technology dimensions of firms' development. However, it is likely that as firms accumulated marketing skills they also learned to meet increasingly sophisticated customer needs and to capture the higher level value-added stages of production.

2. An important background study carried out in the early seventies (Hone, 1974) showed that the main source of export-led growth in East Asian countries was not foreign TNCs but domestic firms, spurred on by foreign buyers from Japan and the USA. The large Japanese buyers, including Mitsubishi, Mitsui, Marubeni-Ida and Nichimen, set up operations in Asian NICs to purchase production capacity as wages rose in Japan in the early sixties. American retailers soon followed: these included J. C. Penney, Macy's, Bloomingdales, Marcor, Sears Roebuck and others. These large buyers were very important for the growth of local firms, often placing orders for 60 to 100 per cent of the annual capacity of exporting firms in electronics, as well as clothing, footwear and plastics. Large numbers of small foreign buyers were also very important to the export-led strategies of latecomer firms.

3. At the time of Wortzel and Wortzel's research in the late 1979 most NIC exporters in electronics had reached stage 4 (clothing, footwear were further behind). Although many firms had taken control of local marketing, product design and quality, they had yet to establish their own brand names. Wortzel and Wortzel believed that stage 5 was "largely theoretical" in the NICs. Today, however, Korean firms such as Samsung and Goldstar have established well-known brand names in some areas. Taiwanese market leaders such as Acer and Tatung have also begun to establish brand names and to manufacture abroad. However, most latecomer firms are behind the leaders in marketing and remain dependent on foreign buyers and TNCs for marketing. For example, Cal-Comp of Taiwan is today the world largest producer of calculators and fax machines. Although it is virtually unknown in the West, Cal-Comp produces rough 80 per cent of Japanese Casio calculators under OEM.

4. Since Gerschenkron's classic work (1962) on patterns of 19th century European industrialization, many studies have examined the phenomenon of latecomer industrialization. However, as with other studies of industrialization noted in the introduction, the contribution of firms, their origins, strategies, structures and methods for acquiring technology are not dealt with on the latecomer literature. This section, therefore, outlines a simple market-technology model for the latecomer firm, based on existing studies of market entry and technology development.

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Science & technology in the new world order

Georges Ferné*

Three major forces operate to define the main characteristics of post-industrial societies:

— The new technological dimension of all economic and social processes, stemming as much from the increasingly effective mobilization of research and development (R&D) resources as, more generally, from the improved capacity of society to exploit opportunities generated by new knowledge.

— The cascade of problems and demands resulting from past economic and technological accomplishments, that require decisions while increasing uncertainty about the future implications of choices.

— The rapid transition to a global economic system characterized by new forms of interdependence.

Although these three forces define the general features of "modernity" and represent a major break from the past, they are deeply rooted in a long history of changes in the scientific and technological systems. Recent historical milestones in this process include the Industrial Revolution of the 19th century, the two World Wars, the Cold War and the energy crisis, but the chain of events extends far back to the dawn of human history and the initial relations between man and technique: the age-old movement that produced modern technology led to a marriage of knowledge and action bringing together the scientific and economic worlds — to the extent that any technological advance can now be simultaneously viewed as an investment and the generation of new knowledge. It is this unprecedented combination that defines technology (the deliberate mobilization of knowledge) as something different from "technique" (the fruit of experience or, according to Braudel, the "taming" of man by man).¹

The change was enormous, as evidenced by the difficulty of expressing it with the available words:

* Organization for Economic Cooperation and Development (OECD), Paris.

¹ Braudel, Fernand. *Civilisation matérielle, économie et capitalisme*. Paris, Armand Colin, 1986. v. 1, p. 291.

"Technology is a word which is taken for granted in English — all the more since 'technique' refers to something quite different, skills or methods. On the Continent, in French, German or the Slavic languages, la 'technologie' seems redundant beside la 'technique' which covers all activities associated with things technical; 'technologie' is much more specialized and refers to more advanced stages of 'technique'. English has no real equivalent of 'technique' and uses 'technology' to cover what on the Continent would be both 'technique' and 'technologie' (...). Recently English has been forced to recognize the inadequacy of its vocabulary: the terms 'high technology' or 'technology-intensive' products began to appear in the economic literature in the late sixties in relation to the analysis of the basis of comparative advantage in international trade by advanced economies; a 'high technology' or 'technology intensive' industry is one which has 'above average' levels in R&D expenditure and in the employment of scientific and technical manpower. Thus, English has coined a new label to describe the most advanced category of technologies, as opposed to those which are produced by the so-called mature industries."²

This label, however, has become less and less significant in recent years, since "mature industries" have undergone massive changes and have often become highly R&D intensive, following a pattern of redeployment of innovation discussed below.

If "technology" thus differs from "technique", it is not in view of their respective objects — since both tend to combine accumulated knowledge, effort, and the use of instruments — nor because of the peculiarities of some industrial branches that would be more "technological" than others, but because of its *nature*: the alliances established with science and with the industrial system in order to open the way for common undertakings.³

These alliances have been made possible by a series of historical developments that can be summarized with three words:

Institutionalization of research, through the creation and diversification of a wide array of specialized organizations such as universities, public and industrial laboratories, technical centres, and so on. These organizations provide scientists with an institutional "menu" so that each type of research can find its most appropriate setting.

Professionalization, because of the existence of career possibilities, so that scientists can reconcile research with personal interest, within the framework of the scientific "ethos".

² Salomon, Jean-Jacques. What is technology? The issue of its origins and definitions. *History and Technology*, 1: 113-56, 1984.

³ Id. *ibid.*

Industrial development, which has made it possible to establish dynamic sets of relations between research and the market.

Technological development and the improvement of production structures and processes are thus now intimately linked and dependent on each other. These interactions reflect the following formula, which illustrates the two challenges being met by technology: the challenge of applying new knowledge produced by scientific research, and the challenge of taking account of the economic constraints under which technique evolves.

Technology = Technique + Research

This is why it would be impossible to give an account of modern technology without referring to a whole archipelago of evolving ideas, practices and traditions as well as know-how that often are more implicit than explicit and cannot be easily brought to light by even the most detailed examination of the successive changes of technical objects throughout a given historical period. If the discussion of modern technology has long tended to focus mainly on R&D, it is because this hard core of technology-related activities is easier to identify, classify, describe and measure. Today's innovation policies are developed in most countries with broader technological horizons: employment and productivity, structural adaptation, industrial relations, flexibility of production processes, development of human resources, social selection of innovations, and so on.⁴

Growing awareness of the complexities of the task does not necessarily mean, however, that national policies are better equipped, and better able, to deal with the difficulties of the day. The more so in view of the fact that it may no longer be realistic to seek national solutions to problems that may be universal.

1. Science for the nations

The history of the "marriage" of science and politics is too well-known to require extensive treatment here. It is sufficient to recall that the marriage was celebrated in wartime (with the Manhattan Project), thus establishing clearly the new nature of science as an instrument of power; that subsequent years were to witness an extension of the instrumentality of science and technology, to extend to the economic sphere; and that the capabilities for extensive exploitation of these new strategic opportunities were essentially concentrated in a relatively small number of rich Western countries.

⁴ OECD. *New technologies in the 1990's: a socio-economic strategy*. 1968.

The concentration of scientific resources

In opposition to the layman's view — and to the occasional claims of scientists — the worldwide research and development (R&D) effort is far from being a truly international one. Research capabilities are concentrated in a small number of countries. More than 90 per cent of these capabilities (measured in terms of R&D expenditures) have always been concentrated in industrial countries.

Throughout the crucial period since World War II (which has witnessed the increasingly systematic harnessing of science and technology capabilities to serve strategic and economic goals), the small "club" of highly industrialized countries have kept their dominant position while strengthening their R&D capabilities. If changes have taken place, they are essentially due to the emergence of a handful of new members such as Japan, Brazil, India, and the "dynamic Asian economies". All these countries have significantly increased their research efforts during the period. One of them at least — Japan — has emerged as a technological leader worldwide and has challenged the preeminence of the "old" industrial powers.

It remains that, if one considers the relatively small number of countries scattered around the world that have both a full-scale S&T enterprise and the ability to take full advantage of it to serve political, economic and social objectives, R&D capacities remain a "local" phenomenon. This "local" phenomenon, however, has had and will continue to have, enormous global implications.

A "local" phenomenon

The total of the world resources allocated to R&D (as measured by R&D expenditures) amounted to about US\$435 billion in 1988. More than 96 per cent were spent in industrialized countries, while all others (essentially the developing countries) merely accounted for the remaining 3.9 per cent of global R&D finance.

This static picture does not pay justice to changes and fluctuations that have taken place in recent decades. Taken as a whole, the developing countries had achieved significant progress in this area until the early eighties, where their combined R&D budgets reached almost 7 per cent of the world total.

However, these efforts have not continued to expand but have been reduced as a result of major constraints, such as the debt crisis and overall economic difficulties. The select group of industrialized countries has thus demonstrated that its preeminence cannot easily be challenged, and that the long-term development of an effective S&T base will remain shaky as long as it is not supported by a modern and competitive industrial infrastructure.

Of all the members of this group, Japan and South Korea have been the most forceful in strengthening their R&D efforts. Their annual R&D budgets nearly trebled (in current US dollars) between 1973 and 1980. By 1980, these two coun-

tries in East Asia together accounted for considerably more than the whole Third World R&D spending. According to more recent statistics, their gross domestic spending on R&D in 1980 represented a tenth of the world funding of R&D in 1980, but had almost reached 20 per cent of it eight years later.

The R&D expenditures of Western European countries have grown almost as rapidly as those of Japan in the seventies, and their share in the world total went up from 21.6 per cent in 1973 to 24.2 per cent in 1980. The average growth rate of many of the European countries remained high in the following years but has shown signs of slowing down. It might be increasingly difficult for Western European countries to retain their strong international position.

Countries of Eastern Europe and the CIS have steadily lost ground as big R&D spenders. In 1973 their gross national R&D expenditures were estimated (in fact, probably overestimated) as representing a third of the global total, but only 27 per cent in 1980 and less than 20 per cent by the end of the eighties. This decline will undoubtedly continue, at least for several years yet.

In relative terms, the North American region accounted for nearly a third of the world's R&D expenditures by the end of the eighties. There had been a period or relative decline in the seventies and the early eighties, but there are clear indications that the new democratic administration will assign a new priority to R&D efforts.

This overall picture underlines the fact that the strategic importance of S&T capabilities is now taken for granted in industrialized countries. It remains, however, that fluctuations over time reflect the difficulty with which political agenda with necessarily shorter-term horizons can accommodate the long-term requirements of R&D efforts. When resources are limited and budgets established on more stringent bases, these countries find it difficult to safeguard the broad continuity of efforts and, even more so, their renewal and diversification to explore new frontiers.

Science in the rest of the world

One striking lesson to be drawn from the developments of the last decades in this area, however, is that the R&D activities of the industrialized countries have grown far beyond the threshold below which their survival, or at least their influence worldwide, could be jeopardized. Whether their combined R&D activities amount to 93 per cent rather than 97 per cent of the world total will not fundamentally affect their capacities to exploit new S&T opportunities. By contrast, the rest of the world can be viewed as much more vulnerable in this respect: its share of the world total managed to reach a peak of 7 per cent at the beginning of the eighties, followed by drastic reduction. And here the difference — from 7 per cent to less than 4 per cent — entails major reductions in the national capacities to take advantage of S&T. The more so in view of available data relating to R&D personnel rather than expenditure, since non-industrialized countries were

reported to employ, at the end of the eighties, 18 to 19 per cent of the world's researchers (scientists and engineers engaged in R&D). This is a much larger share than for R&D expenditure, and it shows how thinly R&D resources are spread. Any reduction in funding probably means that the average scientist in these countries will be confronted with a situation where he (or she) can no longer work effectively as a researcher.

This discussion of average aggregate statistics should not, however, ignore the fact that the non-industrialized world is not homogeneous in terms of access to R&D resources. Some efforts have been made to develop a science and technology-related typology that would bring to light the various levels of S&T bases, reflecting several parameters such as the economically active population; the relative importance of education in science and technology; the sectoral distribution of specialized manpower in relation to science and technology; and the size and structure of the domestic product (GDP) including the share of R&D.⁵

It has thus become possible to tentatively identify countries (a) with no science and technology base, (b) with fundamental elements of a science and technology base, (c) with a science and technology base well established, and (d) with an economically effective science and technology base, notably in relation to industry. The last grouping (d) refers to the highly industrialized countries, while the three others relate to the developing world.

(a) the first grouping of developing countries numbers about 55, including most African countries. These are countries with no science and technology base, which still are at the initial stage of development, with low GDP per capita, low science and technology manpower potential, and a low share of manufacturing of total production;

(b) the second grouping of countries, which have the essential elements of a science and technology base, are in the process of industrialization. With moderate GDP per capita, they have developed a limited endogenous industrial production. Some of them may have a relatively high percentage of science and technology manpower that could be involved in R&D, but the potential is low in absolute terms. This second group represents nearly 40 developing countries and includes Algeria, Ghana, Indonesia, Iraq, Malaysia, Paraguay and Sri Lanka;

(c) the third group of countries, with a high percentage of potential science and technology manpower, have a solid science and technology base and a functioning industrial system. Their GDP per capita is relatively high. This grouping covers about 40 developing countries, including the "newly industrializing coun-

⁵ See: International Council for Science Policy Studies (ICSPPS). *Science and technology in developing countries*. Unesco, 1992. pp. 55-77.

tries" (NICs) in Asia and some Latin American countries such as Argentina, Brazil, Mexico and Venezuela.

Two developing countries are difficult to fit into any of the above categories or groupings of countries. China and India have to be treated separately: they both have a low GDP per capita; at the same time, due to their size, they have a huge science and technology manpower potential in absolute terms, but low as a percentage of total population or in relation to the economy. However, manufacturing represents a large share of their total production.

This typology of countries based on S&T capabilities underlines the fact that the heterogeneity of the developing world. Most of its R&D effort (nearly two-thirds in terms of expenditures) was implemented by countries in Asia in 1980, particularly by those with relatively large R&D systems such as China and India, but also by Indonesia, Taiwan and Thailand. Other countries with small or medium-sized R&D systems, e.g., Pakistan and Malaysia, have also expanded their R&D activities to some extent. By 1988, it was estimated that 75 per cent of the resources allocated to R&D in the developing world were spent by East and Southeast Asian countries. Today, more than 60 per cent developing country researchers are Asians. Africa, and to a lesser extent Latin America, have lost some of the ground they had previously gained. The countries with the largest R&D systems, e.g. Brazil, Argentina and Mexico, had managed to retain relatively high rates of expansion even when confronted with severe fiscal problems. But it is increasingly difficult for them to keep up with the pace set by the leading Asian countries.

The growing market-orientation of Western science

This pattern of concentration of the world scientific resources in Western countries has a number of consequences for them (individually and as a whole), as well as for others.

Science as a national resource

Since World War II, the relationships between science and technology on the one hand, government and economic actors on the other, have been essentially characterized by the fact that they developed in national contexts to produce a unique set of integrated institutions and mechanisms designed to produce and exploit knowledge on an unprecedented scale.

The institutional chain draws its effectiveness from the continuity of activities and organizations involved: various types of laboratories (academic and industrial as well as governmental) that mobilize professional research-workers; systems of education, and in particular higher education, where research plays an essential role in the training of scientists and future managers; large public agen-

cies specializing in the promotion of science as a public good, thus serving special collective interests that would not be sponsored by market forces alone (for example with respect to health or defence, or to basic research and generic technologies); and an extensive and highly diversified tissue of industries, ranging from small and medium-size firms to multinational corporations, each of which plays a role in the generation, diffusion and gradual adaptation of innovation.

The mechanisms include a broad array of funding instruments and incentives enabling public agencies to extend support to various types of R&D activities: individual grants, project and programme grants, contracts, fiscal privileges for R&D activities, provision of risk-capital, and so on. They also include various procedures designed to encourage, for example, standardization, conformance-testing and quality control, in particular in relation to public procurements. All these mechanisms taken together play a crucial part in fostering variety as well as coherence in the generation of new scientific and technological knowledge.

Another mechanisms that plays an essential role in the generation and diffusion of innovations is, of course, the market. Its signals and its rewards, and the ways in which it modulates the prices of various factors, will directly determine the extent to which incentives operate that encourage entrepreneurship and risk-taking. The ways in which various industrialized countries have developed systems that can balance the market requirements and broader political, strategic and social considerations will differ. All of them, however, have singled out domestic, and to varying extent international, competition as a major source of future growth. In the process, the market has become much more than an economic mechanism, to become embedded in the ways in which a national culture will develop its own approaches to risk-taking and innovation.

This cultural dimension adds to the difficulty of emulating the successes of the more advanced countries: the collapse of the Eastern block in Europe, and the subsequent difficulties in its transition to a new economic system, underline the magnitude of obstacles to be overcome. These obstacles become all the more formidable when cultural misunderstandings are coupled with major structural deficiencies. Lack of resources, low levels of skills, few training opportunities, inappropriate curricula in higher education, weak technology supporting institutions, and so forth, may prevent many countries from taking full advantage of their stock of S&T resources.

By the end of the 20th century, only a small number of countries have thus been able to create and maintain comparatively strong national S&T capabilities, in terms of research potential, and an effective system for the exploitation of research results.⁶ Most other countries do not possess the broad range of resources, instruments and abilities that are needed to take part in the interna-

⁶ For a discussion of the notion of the "system of exploitation of research results", see: OECD. *Major R&D programmes for information technology*. Paris, 1989.

tional race for innovation. They have to follow other approaches to draw some benefits from available knowledge and improve the way they utilize and further develop their productive potential.

Most of these countries must thus seek to copy, imitate or simply import incremental technical change. Technical advances in products and manufacturing processes thus depend in general on ideas, capital and consumer goods, services, production methods and know-how, patents and licences originating from abroad.

If the ability to take full advantage of the opportunities generated by scientific and technological progress is thus restricted to a small number of countries, the ways in which these countries (the "Triad" of Western Europe, North-America and the Asian Pacific Rim countries) choose to organize and orient their S&T efforts thus have worldwide impacts. The rest of the world must adjust to them (in terms of organization, priorities, applications, and so on). These activities have become the core of the modern "ecology" of technological progress.

It is no wonder that these achievements are usually seen from outside as a formidable monolith of technological power, so formidable that it is difficult to see how it could be emulated, or how alternative strategies could be developed. The accomplishments are undeniable. There are, however, many weaknesses, and not all industrial countries are equally well-equipped to meet the challenges of the emerging world economy.

The weight of the past

The history of the progressive embedding of S&T into the production and social processes of industrial countries is, as noted in the introduction, an old one. As a result, the S&T systems that operate today can be compared to geological landscapes whose structure includes a number of heterogeneous strata. Furthermore, today's industrialized countries have not followed the same historical paths, and have pursued different objectives. The similarities and differences will affect the ability of each country to meet present and future challenges.

Some of the major landmarks that have designed these S&T systems as we know them today, are:

- (a) the chronology of industrialization and the related nature of infrastructures, with each country following a particular path as a leader or a follower in this or that field;
- (b) the ways in which pre-World War II science has emerged as a profession centred in the universities (USA) or outside universities (France);
- (c) the impacts of World War II in terms of destructions (Western Europe, Japan) or of investments (USA);

(d) the importance of national strategic objectives assigned to S&T activities, that have led to the development of major military R&D establishments in certain countries as diverse as the USA, France, United Kingdom or Sweden;

(e) the importance of the role traditionally assigned to the State as an economic actor, leading to important differences in the relative weight of the government research sector and the statutes of research-workers, as well as in the structure and importance of "national programmes" in S&T;

(f) the degree of internationalization of the national economies, that has determined the range and degrees of the international outlook of scientific communities and industry, and may have in particular been shaped in the past by the opportunities offered by the vast colonial empires of certain countries;

(g) the nature and the evolution of the national consensus about the scope of social concerns to be taken into account by government, as illustrated by the very large social dimension assigned to technological policies, for example, in Scandinavian countries.

All these features are blended in different ways in different countries, so that each has developed its own specific approaches in embedding science and technology in the economy and society. Some of these features — for example, early industrialization coupled with the opportunities offered by colonial possessions and strategic priority assigned to military technologies — may have been a major asset in attaining world leadership in the past, only to become a handicap more recently. This is due to the new trends in technological developments that underpin international trade.

The post-World War II era has been largely characterized by major advances in technology whose development and applications required enormous investments over a long period of time, as has been the case for example with nuclear energy (in both the military and civilian spheres), space and aeronautics, the major wave of innovation in railroads, new mass production processes, and even sectors such as health if one takes into account the massive research programmes and the costs of making effective use of preventive techniques and medication. Central management of technological programmes was an asset in such a context, allowing governments to work hand in hand with large corporations to sponsor the long-term efforts then required, in terms of R&D, institutional innovation, creation of human resources, and so forth.

These efforts could take place in an institutional and economic setting inherited from the past that could readily meet new challenges and adapt to the new opportunities.

A new era started in the mid-seventies with the economic recession following the rapid increase in the costs of oil and other raw materials, at a time when

new industrializing countries, in particular in Asia, appeared on the world scene as major challengers to the "old" industrial countries in their traditional economic strongholds, in sectors such as textile, steel, shipbuilding, automobile, and so on. It very quickly became evident that Europe and North America could no longer take their economic preeminence for granted in any area, but must found new competitive advantages on their innovative capabilities.⁷ The ability to stay ahead of competitors, with ever more effective production processes and a growing range of better products had become the driving force in international trade. This new market-orientation assigned to technology implied that the factors of success were linked to the ability to exploit research results rapidly, adjust quickly to market changes and demand shifts, and shorten the lag between the emergence of new ideas and their application. The ability to mobilize large cohorts of scientists and engineers under the umbrella of national programmes, in highly centralized institutions, was no longer a condition of success. Just the opposite, in many cases: as in the theatre, cumbersome processes and machinery slow down the action...

Countries such as Germany and Japan, that had not acquired major government-sponsored technological establishments, emerged rapidly as the new champions of world trade. Corporations that were managed according to dogmatic principles, had been excessively centralized, discouraged local initiative and felt secure with their market shares — from Westinghouse to IBM — were confronted with major difficulties. Others flourished.

The eighties became a period of major structural change. Monopolies were challenged, either by the market forces at work, or by government decisions to divest, deregulate and decentralize. Attempts were made to reorient large technological programmes that were ill-adapted to cope with the new requirements.

In the United States, for example, the Department of Defence set up a number of projects and new bodies to respond to the Japanese challenge of the Fifth Generation Computer Programme, as did the French with the Filière électronique or the British with the Alvey Programme. These attempts met, at best, with mixed results. When they were launched under a defence umbrella, such programmes could not be exploited on the civilian market as quickly and as effectively as might be needed. In other cases, the technological results of these government-sponsored programmes were not sufficient to generate new industries.

In fact, these programmes came to be criticized not only for their inefficiency in the promotion of commercial innovation, but also in view of the fact that their very existence drove the overall costs of research upwards: such programmes, for example, generated a demand for skilled researchers that had a direct impact on the labour market and the salaries of scientists and engineers.

⁷ OECD. *Technical change and economic policy*. Paris, 1980.

Government programmes could thus be seen as indirectly creating disincentives for firms to undertake R&D activities.

It became rapidly clear that the firm — and not the government — had to be recognized as the main actor on the innovation stage, but that the industrial tissue of the "old" industrial countries often did not provide sound bases for the entrepreneurship needed on the new technological frontier. The government was not in a position to identify markets and promote commercial applications, but would often find itself confronted with gaps in the industrial issue — and the lack of front-rank industrial actors to take up the task.

The major task of public authorities was then to shift to the creation of a general framework of economic conditions, institutions, laws, incentives and basic structural conditions (such as the provision of adequately trained manpower) that would create a favourable environment for industrial adaptation and change. However, the heritage of the past — in terms of attitudes, structures and commitments — could not be dismissed so easily and would probably plague countries for years, if not decades.

The decisive change is that leadership in technological accomplishments does no longer suffice — and may even be self-defeating when pursued as an objective in itself. New economic and commercial rules prevail, which assign a decisive importance to the ability to identify, organize and exploit new knowledge and know-how, wherever it comes from. Scientific knowledge and technological know-how thus become commodities, and success in processing them will often result from the ability to comprehend or imagine all the dimensions of their potential relevance for diverse branches and sectors. Commercial breakthroughs are thus often generated by the recognition of new combinations of technological functions that had not been anticipated (as was the case with Sony's walkman, or with most applications of laser technology), rather than as a product of a well-structured programme covering all stages, from research to application. This type of innovation stems from creative insights, unrelated to research as such, that are not well understood.

The overriding market logic

When drastically new economic conditions emerged in the mid-seventies, such as the rising price of energy, and new competitors from the developing areas, the industrial world sought to formulate a response based on its innovative capabilities. What was not clearly seen at the time was that the new "high technologies" (in particular the information and communications technologies) were going to have such a major impact on the world markets and accelerate a globalization process that will be discussed below. Another major change overlooked at the time was that market forces would increasingly become instrumental in shaping future progress in the most strategic fields where technological expectations

were the highest. As a result, the margins of choice of countries could not but be reduced in considerable proportions.

The logic of the market could not easily be reconciled with other requirements, in the political, social, environmental or cultural spheres. The process of gaining new competitive advantages in terms of economic effectiveness entailed giving up in other areas. The leading countries, such as Japan, and the large multinational corporations active world-wide set standards in terms of innovation rates and productivity that could not be ignored. To meet their challenge meant structural change and reduction of public interventions in the economy, slimming down of the work force with the introduction of more effective production processes, concentration of efforts towards the most promising or vulnerable areas, and so on. The results of these single-minded efforts were to become gradually more and more apparent, with steadily increasing unemployment; impoverishment of the State, that could no longer be taken for granted as a source of support for public goods and long-term efforts; or the reluctant but unavoidable trend towards interdependence of the national economies. The economic recession of the early nineties was to bring all these structural problems to the forefront, because they had by then become major political issues.

The process is still under way, and its consequences for the industrial societies are not clear, although it has become obvious that the very fabric of these societies is threatened, for example, by the rising tide of unemployment, the difficulty of meeting national commitments in public services such as education, health and relief, the dislocation of the rural communities, and the degradation of the urban environments.

At the same time, however, the challenges and opportunities generated by high technologies become ever more pressing. New materials and biotechnologies have already had enormous impacts, and hold the promises of many more to come. However, it increasingly seems that the full exploitation and management of these breakthroughs, as well as, more generally, the future bases of the economy, will be primarily shaped by information technologies.

A little less than five decades ago, it was universally taken for granted that the world had entered a new technological era — the atomic age — that would characterize the second half of this century. And, indeed, nuclear energy has had, for better and for worse, an enormous impact that cannot be underestimated. However, as the end of the second millennium approaches, another technology comes to the fore, with ever more general and far-ranging effects, to the extent that many would define the present era as the dawn of the information age.

Information technology (IT) is traditionally defined as the convergence of electronics, computing and telecommunications. However, data processing capabilities are growing and spreading at such rates that many other technologies can be viewed as having reached a new stage, where they depend on the treatment of information rather than on physical manipulations. This is the case, for example, with new materials or biotechnologies. Furthermore, a growing variety of more

and more powerful sensors will probably accelerate this trend. IT thus, provides new instrumentalities, that make it possible to replace old processes with more effective ones, and to develop entirely new functions and modes of production.

It is indeed astonishing how rapidly the new technology has taken roots and how pervasive its influence has been. This change of emphasis in our view of the contemporary scene has taken place fairly recently. Most certainly, this new awareness is related to the wide-ranging impacts of the new information systems, based on a worldwide telecommunications infrastructure that has come to be characterized as "the largest machine in the world". Recent years have witnessed, for example, the establishment of specific networks for essential services such as banking, financial markets, airlines or data banks to operate in real time. Unprecedented possibilities for data gathering, processing, sharing and distribution have brought new dimensions of global management and flexibility to industry and services.

These technologies thus achieve their full potential only by forming networks, and have two particular characteristics⁸ as a result — "increasing returns of adoption" and "network externalities" — that are intimately related to their interplay with market forces.

The increasing returns of adoption are an outcome of cost structure (heavy investment, moderate operating costs) and the nature of the information technology networks themselves. As opposed to most technological systems of the past (where both the initial investment and the operating costs were very high, as in the case of railroads or energy production and distribution), once a base system is installed (for example telephone lines), it is usually fairly cheap to connect a new subscriber into the network. But the more subscribers there are, the more attractive the network becomes, as illustrated by the history of telephones and fax machines as well as data banks, and so on. Technical improvements have enabled these systems to be connected with existing telephone networks. As a network expands, the cost of connecting new customers diminishes. Increasing returns also occur due to familiarization — the expanding use of a network generates improvements and diversification of services.

Increasing returns can be related to another economic concept, that of externalities, or side-effects. A new subscription to a network entails advantages that are not limited to the subscriber, since all other users also benefit from the simple fact that the network is being expanded. And while these "externalities" are helpful to both firms and individuals (each new subscriber increases the general usefulness of the telephone system), they also benefit the equipment and what it can do (adding fax facilities, for example, makes telephone lines more useful to subscribers).

⁸ See: OECD. *Information technology standards, the economic dimension*. Paris, 1991.

These fundamental features of the economy of networks define a new economic environment where the diffusion of innovation is accelerated and expanded by "bandwagon effects". Increasing returns operate in such a way that there are in theory no other limits to the diffusion of modern innovation than the available infrastructure (telephone lines, or broad-band networks in the near future). These underlying forces are precisely those that generate "globalization", and drive the world economy towards the establishment of a world system of networks. Belonging to this system will be a necessary condition for participation in world trade: not to belong will mean dropping out of the race.

From both the supply and demand side, these varied factors exert strong pressure in favour of standardization. Standards guarantee that succeeding generations of equipment will be compatible with one another and so ensure a satisfactory return on heavy initial outlay. They mean that networks can be interconnected (so profiting from even higher increasing returns) and give users an assurance that their network will continue to improve and grow. Manufacturers and service providers are often understandably reluctant to give in to these requirements and abandon or modify their proprietary systems. It is easy to recall examples of technologies that have occupied the high ground at the expense of rival systems which might have provided better results in the long run — the Qwerty typewriter keyboard, for instance, or the petrol engine for cars.

The stakes are very high, but competing technologies can achieve market supremacy for many reasons, and not necessarily because they perform best or hold out the greatest promise. It can be a question of chance; or a firm may have climbed to the top on the strength of some other technology — IBM supplied office equipment before it went into computers. If this is so, increasing returns of adoption and network externalities work in favour of the dominating system and can stifle competition in spite of its possible merits and/or potential.

In other words, in the context of rapidly expanding networks, a technology does not necessarily achieve preeminence because it is the best; it becomes the best because it is already dominant. The process has been described as "lock-in": a technology gets locked in the market and it becomes impossible for competitors to dislodge them.⁹

The trend towards greater compatibility, however, is overwhelming and reinforced by the demands of users, as evidenced by the progress made in promoting open systems. All the more so in view of the fact that the diffusion of information and communications technologies in all sectors of the economy and society generalizes the peculiar features of network economics outlined above. New production processes and tools, ranging from computer-aided manufacturing and design to flexible automation, and including computer-aided transactions

⁹ Arthur, Brian. Competing technologies: an overview. In: Dosi et al. *Technological change and economic theory*. London, Frances Pinter, 1988.

such as electronic data interchange (EDI), are already instrumental in fostering industrial and commercial networks. This evolution will shortly make itself felt in the production of new consumer-oriented goods and services based on integrated management and processing of data made possible by multimedia, digitalization of the networks and high-speed transmission systems such as ISDN.

Caught in the web created by new networking constraints, all technologies seem to move towards unprecedented levels of blending and coherence. The convergence of these trajectories multiplies the potential rewards as well as the risks: future dominance on the market, or lock-in with an obsolete system, may entail much more than commercial success or failure with a particular system, but condition future mastery of a whole range of technologies at the dawn of the 21st century.

Yet the role of governments in this environment is far from clear. There is little choice but to do all that is possible to remove obstacles that might slow down or stifle the "bandwagon" of innovation which is the compulsory route to full-fledged participation in the new global economy. This entails deregulation (and occasionally reregulation), as well as the adaptation of the education and training system and of other social infrastructures. There is also a great temptation to assist in facilitating choices of specific technologies, and to select national "industrial champions". There are many examples to show that this is a dangerous strategy: at a time of rapid technological change, the immediate future is far from predictable. Wrong choices carry the penalty of wasted investment, if not "lock-in", loss of competitive advantages, and sooner or later the obligation to acquire foreign technologies.

Yet governments are major economic actors. In most countries, public purchases (especially when technological progress generates the need for massive investments in new infrastructures) have a great influence on the emergence of dominant technologies. This indirect governmental responsibility cannot be ignored, and compels governments to become "smart buyers" who will make choices that do not foreclose future options and that will not sacrifice future gains (in terms of possible technological advances) for the sake of limiting costs in the short term. A basic mode of behaviour emerging in many countries (for example in Western Europe) is thus to diversify purchases (in order to safeguard the greatest possible variety of technologies and skills available on the domestic market) while assigning a high priority to compatibility between the various technological options retained.

Additionally, governments play an increasingly important role in ensuring that potential users of new technologies are fully informed of the various alternatives to be considered and of the implications of the selection of each system. It has also become more and more necessary for governments to support actively the participation of national interest groups in the relevant international discussions, ranging from Gatt negotiations to fora where technical standards are being discussed.

The challenge of trading

Networking thus takes place at different levels. There is the technical infrastructure of communications lines combining hardware, standards, protocols and software to evolve gradually into the "information highways" of the next century. There are local networks that have always existed in one form or the other but nowadays increasingly operate in "real time" within electronic communities having common interests. And there are socio-economic networks that use the new information media to establish novel alliances cutting across the boundaries of institutions and specializations in order to develop common strategies.

This new fabric of relations will be enhanced and reinforced by the major priority assigned in all industrial countries to the development of a system of exploitation of research results.¹⁰ Such a system implies the establishment of information and collaboration linkages between a growing number of actors in research, industry, services and trade.

In all industrial countries, governments have tended to shift, in recent years, to indirect actions intended to promote the development of a trade-oriented research environment: legislative and regulatory measures considered to be obstacles to the diffusion and application of knowledge have been lifted (for example, various antitrust regulations were removed in the United States to facilitate pre-competitive research cooperation between firms); new rules were adopted to encourage scientists to take a more active interest in the exploitation of their work (for example by allowing academic research-workers and institutions to apply for patents, even when the invention had been the result of federally sponsored programmes, or by relaxing academic rules so that professors could participate in commercial ventures); incentives multiplied in order to promote science-based industrial activities (i.e. fiscal incentives, schemes to develop employment of scientists by firms of all types, research funding instruments for industry-university collaborative ventures, and so on).

This focus has been accompanied by gradual redirection of the public research support towards new types of programmes, in order to channel efforts onto areas of greater economic relevance. This has affected all types of research activities. For example, institutions that have traditionally been bastions of fundamental research (from the CNRS in France to the National Science Foundation in the United States) devote more and more attention to applied research and strategic research justified by its economic implications. Pre-competitive research activities have multiplied to bring together academic and industry scientists. Certain disciplines receive renewed attention and expanded support, when they relate to the "sciences of the artificial", or "transfer sciences", ranging from mechanical and chemical engineering to

¹⁰ OECD. *Major R&D programmes for information technology*. Paris, 1989.

medicine and pharmacy.¹¹ And economic relevance increasingly becomes an essential yardstick in the assessment of research proposals everywhere.

The rising tide of economic concerns has many consequences. The main point, in a science and technology policy perspective, is the growing influence of industrial considerations on research pursued in academic and government research establishments. Intersectoral collaborations have rapidly increased, to the extent that there are fears about the future integrity of academic institutions. In "sensitive" areas (that is, promising areas in terms of economic potential, as in biotechnology or computer sciences), unprecedented modes of behaviour and attitudes have appeared within universities, and affect the diffusion of research results, and even of ideas, in order to protect patentable discoveries and trade secrets.

The development of a "system of exploitation of research results" is thus coupled with the transformation of the research system into a "system for the production of exploitable results". Such a shift would significantly affect the traditional professional bases of scientific work. In terms of substance, shorter time-horizons would prevail at the expense of undirected, longer-term basic research in the natural sciences. In terms of behaviour, the free flow of information and research results that had been a fundamental feature of Western science since the 18th century would be threatened. Scientific "cliques" would multiply, thus limiting the scope for open discussion of methodologies and conclusions within the scientific community. Ultimately, both the orientations and quality of science could be at stake.

2. The global force

Science as a commodity

In many disciplines, scientists seem to publish less than they used to. In most cases, the support extended to research teams by industry entails some restrictions on the extent and moment of publication of the results. It has become more and more frequent for publication to be explicitly delayed by the contract, so that the sponsoring firm can take a decision with regard to the patenting of any result. In Europe, firms would thus require fairly long periods of time — up to two years — to reach a decision, while the delay is usually much shorter (around six months) in the United States. Overall, various studies have brought to light a decline in the publishing rates in certain disciplines, between the mid-seventies and the mid-eighties.¹² This trend is especially striking in certain key areas, such

¹¹ See: OECD. *Technology and the economy; the key relationships*. Paris, 1992. pp. 35-7.

¹² Ferné, Georges. La science, une nouvelle marchandise. In: *La Recherche*. Mars 1989.

as electrical engineering or biotechnology, that have enjoyed expanded funding during the same period.

New strategies are being developed for the management of scientific information in the "computer age". New instrumentalities open the way for easy screen-to-screen communication between researchers. The "grey literature" used to be unpublished material circulated under the form of manuscripts for discussion with colleagues. It has now become electronic, and a substitute to publication when its access is restricted to members of a network that includes industrial and non-industrial scientists whose interests extend to commercial applicability at least as much as to the advancement of knowledge as such.

Thus, commercial success may now be less a direct function of the ability to produce new knowledge, than of the ability to access the right information (and hence to belong to as many productive networks as possible) and to recognize the relevance and potential synergies of scattered elements of information. New industrial structures based on "flexible specialization" make it possible to adjust to new results and integrate them rapidly in order to acquire a temporary monopoly that will undoubtedly be challenged soon by other actors. Hence the relentless quest for ever newer data and ideas. No single organization can hope to master alone the expanding flow of results stemming from international research, the more so when the circulation of these results is increasingly channelled by their producers. It thus becomes unavoidable to trade with others the possibilities of gaining access to vital information. This constraint explains the development of cooperation schemes between industrial competitors ("coopetition"), where each participant stakes its future on its felt greater ability to manage and exploit the results that *might* become available. It also explains the extraordinary development of industry-university relations since the end of the sixties: industries do not support academic research merely to benefit directly from its results, or to establish a channel for the recruitment of graduates, but rather to create, through the team under contract, a scientific channel to the relevant research worldwide.

It is no wonder, in these circumstances, that governments have attempted to step in and take part in the "management and control" of the precious and short-lived resource that scientific information has turned out to be.

Government controls were first implemented in connection with transfers of technologies considered to have military, or both military and civilian, implications. Cocom was thus established in 1949 to monitor technology flows towards the communist countries. Since 1989 and the collapse of the Eastern bloc, the list of strategic exports under control has been shrinking, and the days of Cocom are obviously numbered.

Other concerns, stemming from the potential dangers of exports of sensitive technologies to countries of the South, however, have prompted the creation of additional control mechanisms. The Nuclear Suppliers Group (NSG), or London Club, was established in 1975 to promote nuclear non-proliferation. The Australia Group was created in 1984 during the Iran-Iraq war, in connection with chem-

ical and biological non-proliferation. Another group was established in 1987 in the area of missiles technology non-proliferation (Missiles Technology Control Regime — MCTR). All these committees suffer from the fact that they have different memberships mainly limited to Western industrial countries. The issue of extending world control to allow for the participation of Eastern European countries, and of others such as China and India, is now on the agenda.

This type of control focuses in principle on technology that has military implications, although it is not always easy to draw a clear line between "military" and "civilian" technologies. The non-proliferation efforts of industrialized countries have occasionally been suspected of also striving to protect economic monopolies and interests. A counter-argument is that major industrial firms, in industrial countries, often claim that these controls are excessive.

This debate is far from being exhausted, since a new dimension of government monitoring of the circulation of information, however, has resulted from growing awareness of its economic stakes. More and more countries have been attempting to limit the "leaks" of scientific information that were thought to benefit competitors. In the United States, for example, foreigners have occasionally been refused access to scientific conferences. A controversy has developed over the allegedly excessive number of foreign students taken on by universities. The restrictions placed by sponsoring firms on the publication of research results are also intended to prevent the early disclosure of economically strategic information.

The rapid advances of computer sciences, materials and biotechnologies challenge traditional concepts relating to intellectual property rights. Patenting of living organisms or of gene sequences, the extent of software protection through copyrights, the regulations covering appropriation and access to data bases are among the major issues debated, for example, in the framework of Gatt. Issues such as data banks, data flows and data networks, privacy protection, patents and trade secrets, copyrights and service delivery, standardization and information security are also increasingly debated in national and international fora. Another important aspect is related to technology transfers, and the various restrictions that often accompany the provision of a new technology.

The trend is unmistakably towards a multiplication of rules governing appropriation of information and the information market. Scientific knowledge cannot be expected to remain untouched by this worldwide evolution, with many major implications for all countries, and in particular for developing nations. The new system of control of the diffusion of information, which is gradually being developed worldwide by the major owners of new technologies, is still rapidly evolving, and remains characterized mainly by implicit modes of behaviour rather than explicit regulations. Its impacts are, therefore, very difficult to assess.

They are, however, at the heart of a globalization process that redistributes power and influence, as well as the bases of power and influence. The conversion

of a number of countries, in Eastern Europe and in the developing world, from central planning to market economies illustrates spectacularly the end of a bipolar world and the growing impact of international trade. It provides, in fact, an illustration of the relentless pace and unprecedented nature of the "globalization" process.

Developments in IT have already had a major impact on international relations, in a wide range of fields extending from cultural to economic exchanges, and including areas of concern affected by the new technologies (such as the legal issues mentioned above, connected to privacy protection, transborder data flows, security, and so on). IT has played, and continues to play, an essential role in world trade and the current development of "globalization". This is not merely due to the rapid expansion of IT-related trade,¹³ but also reflects the strategic role increasingly played by computer-to-computer relations as a basic infrastructure for international exchanges of all types. National policies cannot ignore this worldwide dimension: there are global problems to be addressed by IT, and new challenges resulting from the development of an IT-based world market, that can only be met through international action.

The global nature of many problems that call for IT-based adjustments and responses, provides a powerful stimulus to international cooperation:

— Environmental problems are drawing increased attention and the magnitude of the threats is such that joint international action is required.

— There is a need to avoid costly duplication of R&D efforts that could be more effective if undertaken under multilateral cooperation schemes.

— The greater integration of national economies generates new trade patterns and the emergence of transnational industrial alliances and information flows, that may call for the formulation of new international understandings and rules of the game.

— International efforts are also needed to involve late-industrializing countries in the development of new world IT infrastructures, and allow them to benefit from the resulting growth opportunities.

It remains, however, that the new global economy is not homogeneous and that a relatively small number of regions and countries exercise enormous influence.

¹³ OECD. *Trade in information, communication and computer services*. Paris, 1990.

The new centres of economic power

If the world economy has become much more integrated and interdependent, several well-defined centres of science and industrial technology exercise a major influence.

It has become more and more apparent that three dominating regions of the world economy largely determine the patterns of R&D, innovation, and high-technology trade. Each of these regions represents a coherent system of industrial development and production, even though it may be increasingly dependent on the others.

There is a Western European economic space, a North American one, and an East Asian industrial space with Japan at the centre. Each has its own sizeable industrial base and technological "strong points", and each has developed ambitious policies to retain its lead in certain areas, and to regain lost ground in others. Based in these regions, about 1 thousand major corporations control more than half of the world's manufacturing and almost two-thirds of international trade.

From a statistical point of view,¹⁴ little is detectable of the "global reach" of large industrial corporations which operate from these three major industrial regions. No indicators are available at firm or at industrial branch level to bring to light the role of science, technology and innovation in the penetration of corporations in the different regional markets for products and services. Nor are there statistics of the transfer of technology and other knowledge generated by the need of these firms to gain access to foreign supplies and new sources of production. The operations by corporations on patent protection, licence agreements and royalty issues are not recorded in any data bases.

Yet these corporations based in the three main economic regions are the most important actors that operate worldwide by way of modern technology. Foreign investment, sub-contracting and outsourcing have become standard practices for these companies, and provide a channel by which small and medium-sized firms in the three regions — and beyond — have little choice but accept linkage to the same systems. New technologies are at the root of these developments.

The new patterns of global competition

Information technology promotes the internationalization of production and markets because it makes it possible to achieve new levels of economies of scale and scope; because, through flexible systems, it provides instant adaptive capacities to adjust to market fluctuations; because it removes barriers to the smooth

¹⁴ See: Annerstedt, Jan. Measuring science, technology and innovation. In: Salomon, Jean-Jacques et al. (eds.). *The uncertain quest*. Tokyo, United Nations University Press, 1993.

flow of services and finance across borders; and because it allows for real time monitoring and management of the most distant facilities. These features have generated a dynamic process of internationalization of economic activities that affects industry, finance, services, culture, and so forth, on such a breadth and so comprehensively that there is a clear discontinuity with respect to the past. Hence the notion of "globalization", a notion that has been strengthened by the emergence of a number of "global problems" resulting from threats to the planetary environment.

The rapid diffusion of IT thus fosters a new regime of interdependence in international relations. Each country becomes more and more vulnerable to the impact of decisions taken elsewhere — by other countries or by multinational firms. Informatization and computer-to-computer communications provide decisive instruments for the development of this new world structure that arms giant firms with the techniques required to manage, transfer and process technical and economic information worldwide and on an interactive basis. This will obviously affect the international division of labour and production as well as international trade, changing the patterns of industrial ownership and control, altering the competitive standing of individual countries and creating new trading partnerships.

The impact of these new technologies cannot but become more and more extensive. This is not surprising. "Information activities of one kind or another are a part of every activity within an industrial or commercial sector, as well as in our working and domestic lives. Almost all productive activities have a high information intensity (some involve little else, such as banking or education), so information technology is capable of offering "strategic" improvements in the productivity and competitiveness of virtually any economic or social activity. Information technology is universally applicable."¹⁵

Mutual adjustments are taking place worldwide, between technological change, industrial organizations, financial and labour markets, as well as governmental and non-governmental institutions. They will obviously affect all nations: those that will be able to take full advantage of the new opportunities, those that will lose ground in the competition for global technological preeminence, and those that will find it ever more difficult to close the gap that separates them from the more affluent societies. A number of consequences are already clearly apparent:

- The complex pattern of industrial alliances for research, production or marketing, which ignores regional groupings to establish pragmatic coalitions of interests that raise the threat of uncontrollable cartellization at world-scale.

¹⁵ See: Pereira, Paulo Rodrigues. New technologies: opportunities and threats. In: Salomon, Jean-Jacques et al. (eds.). *The uncertain quest*. Tokyo, United Nations University Press, 1993.

- The difficulty of regulating "transborder data flows", that may include, for example, strategic information as well as speculative funds that can be transferred without control through a broad variety of proprietary communications systems.

- The general weakness of governments when confronted with this "globalization" process that obviously holds the key to future growth while challenging the sovereign rights of nations.

- Significant changes in the blend of skills required by the new technologies, accompanied by new possibilities for the delocation of plants and acceleration of automation, thus generating simultaneously unemployment and labour shortages.

- The growing importance of software and service activities relative to more traditional manufacturing.

- The proprietary nature of much of the new information technologies: key technologies cannot be acquired by new entrants, even if they had the skills; and, even if the technologies in question could be acquired and mastered, established markets could not be penetrated.

At the same time, however, there are many features of the IT technologies that threaten the industrial world with major disruptions and threats. The process of structural adaptation, in itself, generates immense social difficulties that cannot be easily overcome, as shown by the rising unemployment rates.

However, there may be even more basic and fundamental forces at play. The multiplication of all forms of network that seem to extend worldwide the marketing capabilities of the industrial countries may come to operate in unexpected directions. As noted above, the labour markets of most industrial countries are characterized by the coexistence of unemployment and shortage of certain skills. Yet these skills are available elsewhere and the new computer-to-computer communication infrastructures make it possible to employ these skills, wherever they are, without delocation of industries. Some Western European firms, for example, have already taken advantage of "teleworking" to employ accountants in the Philippines, or software developers in Hungary and India.

These new trends illustrate what may be a dominant pattern in international competition in years to come, characterized by the disappearance of many traditional links between employment and location. In such a new configuration, education systems, low salaries, and the availability of adequate skills and competence, may become a decisive competitive advantage as such. But what are "adequate" skills? The ability to choose wisely in what areas to specialize, and how, may well turn out to be the essential key to economic success in years to come.

3. The future of nations

Compulsion and liberty

No country can at present afford to isolate its scientific and technological effort from those of others. Yet, in order to be able to follow the international progress of knowledge and skills, each country must retain its own specific capabilities, that will often require the creation and maintenance of an R&D base in the areas considered essential for its future.

It would thus appear that any national technology policy must acknowledge that the existence of "margins of liberty" (that is, areas where it can decide to acquire strength or not), is conditioned by the acceptance of "compulsory choices" (in other words, "core" technologies that must be mastered in order to have minimal access to the technology in question).

Looking across major national and international scientific and technological programmes, in Europe, North America or Asia, one in fact discovers quickly that they all have a common core reflecting the need to acquire control of a basic technology. However, once this is acquired, different degrees of autonomy and specialization can be exploited.

This can be illustrated by the examples of information technology, biotechnology and materials.

— Information technology is a heterogeneous grouping of areas such as micro-electronics, data processing, telecommunications, and computer-assisted manufacturing. In *microelectronics* the common thrust is to design smaller chips while minimizing the production costs through greater circuit integration, improvements in semiconductor design and fabrication, or silicon and gallium arsenide applications. In *data processing*, applications are turning to expert systems (intelligent machines), intelligent robots and speech recognition. Each of these applications must be mastered by anyone wishing to be in the running in future, if only to be able to take full advantage of the diffusion of new products as soon as they come on the market. Whether concerning Japan's INS programme, or the European Race programme, or the more recent Clinton initiative in the United States, the major objective in *telecommunications* seems to be the establishment of integrated services digital networks (ISDN) that will in future meet the requirements of all users (firms, services, administrations and consumers) by carrying sound images and texts at very high speed and very low cost. *Computer-integrated manufacturing* is now based on numerical control machines, industrial robots, computer-assisted design and manufacturing systems and visual tactile recognition devices. A large number of national and international programmes reflect these priorities.

— Biotechnology also is not a unified discipline, but a combination of different research areas and techniques based on joint contributions from biology, chemical engineering, medicine, plant and animal physiology, and so on. Exploiting the full potential of these advances essentially requires mastery of *recombinant DNA*, *cloning* and *fermentation*.

— New materials result from the increasingly varied and sophisticated demands of modern industry, coupled with the potential of information technologies applied in design and production processes. Basic technologies must be acquired to generate key materials such as *composites*, *ceramics* and *polymers*.

These three areas have become as many compulsory gateways for access to the arena of modern industrial development. They have striking common characteristics that underline the difficulties of the task:

— In all cases, sophisticated applications of information technologies are required.

— There is never a single scientific discipline or technological speciality at stake, but a broad range of different areas of knowledge and know-how, requiring advanced skills on a large and heterogeneous front of interdisciplinary expertise.

— The application of new knowledge in these areas does not involve a straightforward relation between research and a particular sector of the economy, since all three technologies have implications for all spheres of human activity.

— Research in these three areas is predominantly "problem-oriented", and the major breakthroughs of the last decade have mainly resulted from socio-economic pressure to provide answers to specific questions.

— All these parameters are not stable, but evolve very rapidly with worldwide advances in research.

— Much of the relevant knowledge, however, is of a proprietary nature and either cannot be acquired cheaply, or cannot be acquired at all at the appropriate time.

If the economic future of all countries depends on their ability to master at least some key elements of these technologies, the task is by no means easy. It will require a high level of skills in a great variety of fields — and hence substantial adaptations of the educational and training systems. It will also require the development of research capabilities in strategic areas, at least at a level that allows the effective transfer and adaptation of knowledge from abroad. To be

productive, these efforts will need to be pursued in close relation with social and economic actors, in order to facilitate the transfer of questions as much as of results. And, finally, it will also be necessary to develop appropriate channels to remain continuously informed of world developments in research. Such channels will depend on the establishment of networks and collaboration between the national industrial and scientific efforts and their international counterparts. Hence a paradox: in order to acquire or retain a competitive edge (a condition for the safeguard of national identities), any country must actively explore all possible channels of cooperation with others, in research perhaps even more than in other areas. This is as much a consequence of the proprietary nature of a great part of the research results in high-technology than of the rapid rate of production of new knowledge in these fields.

Towards new forms of research cooperation

The rapid development of a global economy has reinforced the belief that the days of the nation-state are numbered. And yet, simultaneously, there is no lack of evidence worldwide of the resurgence of many forms of nationalism, often leading to conflict and open warfare. It would seem that progress in achieving world growth based on the exploitation of the potentialities of economic interdependence will depend on the ability of the international community to achieve a working compromise between the requirements of the global system and the preservation of national identities.

Thus, governments everywhere attempt to define their new role. One thing, at least, has become ever more clear: no country can expect to be an effective actor on the world economic scene without the scientific and technological resources required to keep up with, and even to generate, an uninterrupted flow of innovations. And all countries also find that the ability to compete effectively goes hand in hand with the ability to cooperate. The collapse of the Eastern bloc at the end of the eighties is a dramatic illustration of the penalties to be paid, even when scientific and technological resources are in principle abundant, for isolation from world trends, information channels and trade.

Western European countries began their march to economic unity by joining forces in the key sectors — coal and steel — of the post-war world, gradually to extend this cooperation to nuclear energy, space, and subsequently to the whole range of science and technology activities, in education as well as in research. The recent creation of the North American Free Trade Area represents another milestone in this trend towards cooperation at the scale of continents. Japan has multiplied collaborative ventures with other Asian countries through the Asian Pacific Economic Cooperation (Apec) system, and often demonstrates its desire to join forces with other members of the "Triad" to explore the most advanced frontiers of knowledge. And it is probably no coincidence if other countries that

lag behind, economically as well as technologically, are often those that have not managed to generate and join effective regional cooperation schemes.

For, once again, cooperation and competition, in today's world, are two sides of the same coin. Cooperation is, of course, an unavoidable route when resources are limited and a single country cannot bear the full cost of the large R&D investments that are often required in key areas. In less tangible ways, cooperation is also required in order to develop in common the basic rules that will make it possible to benefit fully from a "regulated" globalization process: common understanding and joint decisions at international level are necessary in order to remove barriers to the expansion of trade and establish a world trade system whose excesses (in the form of excessive monopolies, or savage competition) could only generate adverse national reactions taking the form of open or hidden protectionism. To "tame" globalization will require that greater attention be paid to developing more fair and effective international "new rules of the game" in areas as diverse as intellectual and industrial property rights, transborder data flows, privacy protection, antitrust, standardization, technological risks, environmental hazards, access to data, and so forth.

Discussion of many of these questions are time and resource-consuming, as well as highly technical. These negotiations are often left to technicians representing a small number of countries. Others might be well-advised to take more active interest, so that their specific interests are fully taken into account at the appropriate time. The future of nations depends on this ongoing process of development of new rules for the global society, that is intended to establish the general framework within which each country should be in a position to define its own approach to economic and technological progress.

In relation to research, for example, the absence of common rules has serious implications. The exploitation of the findings, which is the normal outcome of any cooperative scheme — at national as much as at international level — must be shared out on an equitable basis. When the project is concluded, it must be possible to measure the input and benefits for each concerned: for instance, a line must be drawn between the knowledge and know-how initially supplied by each participant, or *background*, and the results of the shared work, or *foreground*.

This distinction becomes even more blurred when the partners are reluctant to disclose the extent of their skills in detail for the simple reason that they do not wish to say too much to potential future competitors. Japanese firms taking part in R&D projects have been known to consign information on their background knowledge in sealed envelopes to be opened only in the event of disagreement over the allocation of results.

The procedures used for sharing out the results are of vital importance for determining the patent rights or potential licensing rights of each party concerned. The diversity of approaches currently used in different national and international programmes is therefore likely to lead to conflict.

This is compounded by the fact that programmes are evolving. At the start, most programmes result from a strategic plan for advanced research. The intent is to pool knowledge and research means among teams of researchers from private firms, university or public laboratories in order to generate basic knowledge in a new technological field. The aim is to move ahead in a generic technology (e.g. genetic coding, or superconductivity) without any specific commercial outlets in mind at the start. Research is viewed as "pre-competitive". However, technology — even of the most "generic nature" — is never totally divorced from strategy and commerce. As the project develops, economic implications and application opportunities will become more and more obvious. The cooperative programme tends to shift to more market-related goals, and will thus meet even greater difficulties in sharing out research findings. The future of the participants — be they countries or firms — depends on their ability to anticipate such situations and solve these problems equitably.

The challenge of defining priorities

"There was a time — not so long ago — when governments hoped to be able to programme, and even plan, scientific and technical progress with the aim of being able to control the whole chain of initiatives and events leading from the production of knowledge to the launching and diffusion of products."¹⁶ The common assumption that there actually *was* such a chain, mechanically linking basic research to innovation, was certainly naïve oversimplification. It remains, however, that the overall context in which science and technology policies are made has changed drastically since the sixties and seventies, to a large extent as a result of the progress achieved in the new "high-tech" sectors. For many observers, the world has entered a new "techno-economic paradigm", and is presently engaged, as a result, in a process of major change comparable to the Industrial Revolution of the last century, but which may turn out to have even deeper implications, in view of its global nature.

The world economy is thus being remodelled, and the interplay of technological, economic, social and political factors is so complex that even the immediate future is difficult to forecast. Instant adjustments to unexpected shifts have become a daily requirements for individuals, firms and other institutions, as well as for governments. In this climate, the stress is on structural adaptation, flexibility, deregulation, decentralization, initiative... In the absence of clear markings of the road to be followed, it becomes indeed very difficult for each country to arrive at rationally defined priorities.

And yet such priorities are unavoidable in science and technology, with regard to education and the provision of skills as much as with respect to

¹⁶ OECD. *Major R&D programmes for information technology*. Paris, 1989. p. 12.

research-related activities, ranging from the selection of programmes to be launched and implemented domestically, to the choice of areas where cooperation and/or licensing would be needed. Such choices will be all the more difficult in view of the fact that they may only be expected to have a medium-term or even long-term impact.

New types of approaches to the day-to-day monitoring of rapidly evolving technologies are needed. As noted above, a careful analysis of the main trends in each of the new major technological areas will bring to light "margins of liberty" and areas of "compulsory choices". This understanding is of essential importance to all countries since it will set the technological framework against which decisions can be arrived at. In other words, the challenge is "to bring out the extent to which the options that can be envisaged are in fact circumscribed by a certain number of lines of force that do not allow very much diversity in the choice of objectives and impose a certain logic on all approaches".¹⁷

The identification of these "lines of force" has been referred to as an exercise in "technological landscaping",¹⁸ whose task is to identify peaks that cannot be scaled, mountain ranges that *must* be crossed, and valleys that might make it possible to circumnavigate obstacles. In order to be effective and contribute to the formulation of the national technological strategies, it is clear that such an effort should be developed on a continuous basis, since it is concerned with a constantly shifting landscape; that it should be established in close communication with the highest levels of government concerned with industrial and technology policies; and that the results of its work should be broadly publicized and available to all relevant public and private actors whose decisions are affected by, or will have an impact on, technological change.

Finally, such an activity needs to be directly articulated with more circumscribed efforts undertaken by different groups to explore certain aspects of technological change. These related efforts range from the technological "search" activities of firms hoping to keep abreast of the "state of the art" in their specific branches, to technology assessment attempts reflecting environmental and social concerns.¹⁹

Technological landscaping, however, cannot be expected to make a real contribution if it serves merely to collect and redistribute data on innovation. Landscaping implies a construction, an effort to make apparent chaos intelligible. Thus, the main challenge of technological landscaping is probably to organize the information collected in a way that will facilitate insights in areas of national interests. There are, at present, no ready-made recipes or formulas for such an achievement, and one may hope that practice will gradually improve. But the

¹⁷ Id. *ibid.*, p. 13.

¹⁸ Id. *ibid.*

¹⁹ See: Brooks, Harvey. Technology assessment. In: Salomon et al. *Op.cit.*

magnitude of the theoretical and practical difficulties should not deter any country from launching this type of effort, in the direction most appropriate in view of its national endowments and concerns.

4. Conclusion

All countries have to adjust to an international environment which has become more and more volatile and less and less predictable. The ability to mobilize science and technology is now broadly acknowledged as an essential asset, but technological advances proceed so rapidly and on such a broad front that they contribute to increasing uncertainty about the future. Brazil has in the past devoted considerable resources and energy to the development of scientific and technological resources. In several cases, the country has followed strategies of its own, which have given the national S&T effort some unique features and have succeeded in placing Brazil as a world leader in several areas.

Although the author of this chapter is very far from being fully informed of the many dimensions of Brazilian science and technology, it would seem to him that the major and most urgent task ahead is to take advantage of these accumulated resources (in terms of qualified personnel, institutions, expertise, skills and know-how) as competitive advantages for successful participation in international trade. The difficulty of the challenge is to seek greater integration in international exchanges of technology, goods and services, while seeking to strengthen the contribution of S&T resources to the development of the Brazilian economy and society as such.

The very first priority should be to encourage and strengthen the institutional chain that unites the system of production of scientific and technological knowledge with the economic and social systems where the results will be considered for application.

In order to increase the general effectiveness of the national research system, the professionalization of science and technology still needs to be encouraged and advanced. Broadly speaking, the research profession needs to be even more explicitly recognized as a legitimate and essential activity within society. On the one hand, this will require systematic efforts to facilitate public understanding of the specific needs and national implications of scientific work. On the other hand, public recognition should be translated, from the perspective of the scientist, in terms of adequate salaries, career prospects, a sense of belonging to a national scientific community, and so forth.

Professionalization of research also requires effective institutional settings (universities, government research establishments, industrial laboratories), where the basic requirements of scientific work are satisfied (in terms of equipment, technical assistance, facilities, and so on), while supplementary funding can be obtained for specific projects. In spite of the high priority assigned to applications-oriented work, pluralistic funding will be essential to leave the way open

for the support of different types of research in a great variety of sectors. This sort of diversified support is an essential condition for the development of a flexible research system, that will be able to reflect the variety of national needs while allowing space for undirected, more basic research which is the breeding ground for future innovations.

In this connection, special attention should be paid to university research, as a focal point for the training of future researchers and the pursuit of non-oriented research.

The federal structure of the country should provide an opportunity to foster decentralization and diversity in research and training approaches. It is also at this decentralized level that initiatives could be taken to reinforce various "bridges" between research, the society and the economy, in order to encourage application of results to the solution of local needs. This type of linkage is all the more essential, because it should often provide a favourable setting for the emergence of new ideas, experimentation and demonstration based on generic technologies that are nationally available. When appropriate incentives are available, such local environments can become hatcheries for innovations that draw upon the national stock of knowledge and know-how to respond to specific economic and social demands. The potential of such innovations for lucrative marketing abroad should not be underestimated.

The diffusion of new results and technological developments also needs to be systematically pursued at national and local levels, to be brought to the attention of small and medium size firms, farmers and forest managers, exporters, and so on. In each case, specific arrangements will be needed to ensure effectiveness in reaching the target group. Extension services developed in other countries in rural areas could provide a model to be adapted. In any case, policy analysis and evaluation should be conducted on a continuous basis to bring to light areas of possible convergence between research applied to national needs and market-oriented research and applications. Various schemes will be needed (from "factory-nurseries" to venture capital opportunities), in order to encourage a new export-oriented spirit and facilitate the commercialization of new products.

These efforts should, in particular, be closely related to technological landscaping activities conducted in close relation with policy-makers. These activities should provide essential inputs for the definition of national priorities in research and training. Their results should be broadly available to the public.

Export-oriented attitudes should in any case be systematically encouraged in research institutions. This might require deliberate efforts to promote industry-university relations in education and research and to provide assistance to scientists for the filing of patents, and so on. Scientists and engineers should be able to contribute directly to innovative industrial ventures.

Export-oriented institutions should be reinforced in areas such as standardization, quality control and conformance testing. Special measures should be implemented to ensure that the responsible bodies are adequately funded for their

national and international activities, and remain closely connected to both science and industry.

The implications of the major goal of creating a "networked society" — both nationally and extended internationally — should be explicitly recognized in all areas of public policy. Special decisions will probably be required in order to promote "open systems" in government informatization programmes.

Greater attention will need to be paid to the implications of public purchases at national and local levels. The public purchases system should be established on a basis that fosters technological creativity as much as economy of resources. All sectors of government activity should, in particular, be invited to explicit and articulate their technological requirements. The overall requirement of "vintage compatibility" (between different generations of technologies) will be especially important in connection with the development of social infrastructures (in urban as well as in rural areas): initial investments, even when modest, should be designed not to preclude subsequent additions of, and integration with, more modern and extensive components. A basic principle to be strictly adhered to would thus be to always "leave future options open".

All these decisions will usually involve substantial contracts with suppliers and constructors. It should be remembered that contracts allocated competitively (on the basis of a "bids and proposals" procurement system) have a positive effect on innovation capacities. While non-competitive procedures for the allocation of public contracts usually do not.

Beyond the large but still limited area covered by public purchases, all industrial societies need to increase deliberate efforts to generate more diversified demands for the application of new technologies in industry and services. Various incentives and technical assistance schemes will be needed for this purpose.

Finally, adequate resources need to be specifically allocated to the pursuit of international efforts, as natural extensions of national activities in science and technology. Careful consideration, however, needs to be given to the procedures and mechanisms most appropriate to maximize returns.

United States science and technology policy: the effects of a changing international environment

*Eugene B. Skolnikoff**

1. General setting

Political and economic changes

The momentous changes on the international scene in recent years form the essential background for an assessment of the science and technology policies of the United States: what they are and what they are likely to become. Largely as a result of evolving international relationships, the United States, with by far the largest expenditures of any nation on research and development, is now engaged in a major reexamination of its science and technology policies, with likely substantial effects on relations between the United States and other nations, and particularly with the developing countries of the South.

The most obvious political change on the international scene is the end of the Cold War that has greatly reduced the rationale for what has been the majority of research and development (R&D) funding by the United States government (defense takes some 60 per cent of the federal R&D support in the current 1993 fiscal year), and for about 30-40 per cent of all funding, private and public, devoted to R&D (total public and private resources devoted to R&D in FY 1993 are estimated to be about US\$150 billion).¹ The reduction in the overwhelming security threat comes at a time that has seen a major increase in the level of international economic competition the United States faces, particularly in technology-related fields. The once dominant American international trade position has given way to negative trade balances, even in

* Massachusetts Institute of Technology.

¹ Statistics on R&D expenditures are not wholly accurate, nor up-to-date. However, they do provide adequate order-of-magnitude estimates. The best sources are found in OECD (Organization for Economic Cooperation and Development) reports, reprinted in *The OECD Observer*, for example in *OECD in figures: supplement to the OECD Observer*, N° 176, June/July 1992, and in National Science Foundation (NSF) documents, such as *International science and technology data update: 1991*. Washington, D.C.; NSF, 1991. (Special Report NSF 91-309.)

high-technology products which had been considered the hallmarks of United States comparative advantage.²

The reduced security concern and the rise of economic competition have markedly altered the climate for S&T policies. The overt demand for economic returns for investment in science and technology is rapidly growing, while the funding for defense-related R&D, though not likely to fall precipitously, will certainly be a smaller portion of the total and will increasingly be related to economic as well as security purposes. New programs directly related to economic goals will be added, and existing programs will be recast or expanded to emphasize economic objectives. The election of an enthusiastic new administration committed to a greater government role in the economy will amplify this shift (these matters will be revisited below in detail).

Other developments in the economic situation have necessarily also had significant effects on American S&T policies. The worldwide recession of the late eighties and early nineties and the enormous growth of annual budget deficits and accompanying increase in the national debt constrained the scale and nature of government funding for R&D, though not as much as might have been expected; gross resources devoted to R&D outstripped inflation steadily until the current fiscal year (according to President Bush's budget, which will be modified later this Spring by President Clinton).

The rise of regional trading blocs, first in Western Europe, and now slowly in the Western Hemisphere also may over time alter the context in which policies for S&T are considered. The European Community has organized a wide array of cooperative R&D projects among its members, at times with exclusion of participants from outside the Community. If that pattern continued, and Nafta (with a possible extension to the whole Western Hemisphere) materialized, it is possible that R&D policies in general would become more focused on regional economic, trade and cooperation opportunities. Failure of the Uruguay Round of trade negotiations would carry the danger of unleashing protectionist forces that would make this retreat to regionalism more likely to come about.

Working in the opposite direction is the unprecedented degree of international integration of national societies that has become one of the defining characteristics of today's world. It is particularly relevant in economic matters, but is evident in essentially all facets of modern life, including social, cultural, technological and environmental dimensions. Whether it be called integration or interdependence, the phenomenon is well recognized by governments, by analysts and by the public at large. Science, always considered by its practitioners to be an international endeavor, nonetheless also is affected in innumerable ways by this new level of inescapable interaction among States.

² OECD in figures. pp. 56-7.

Conflicting views of the future can be drawn from this steadily more intense integration that is characteristic of the world scene. Will it mean the ultimate erosion of the nation-state accompanied by the rise of non-state institutions (governmental and non-governmental) with enhanced authority and responsibility? Or, conversely, will an aggressive nationalism develop, with a return to hegemonic rivalries and emphasis on achievement of national, as opposed to international, goals perhaps organized in a regional structure? Or, some combination of both?

This is not the place to attempt to forecast which view, or whether some combination, is the one more likely to materialize, and when.³ However, it is important to observe, notwithstanding dramatically intensified international integration, that science and technology continue to be supported through a process that is primarily national, that the motivations for the support provided by governments are intended to serve the objectives of the State, and that by and large the motivations for private-sector support also are oriented to the purposes of the State since the fortunes of firms, even in an era of growing internationalization of industry, are dependent on the well-being of the nation in which they are primarily based.

Thus, the underlying fact is that the resources allocated for science and technology — public or private — are still dominantly national in purpose, are determined in a national policy process, and are allocated to serve national goals. This pattern will undoubtedly remain as it is well into the future.

Developments stemming from scientific and technological change

The fact that international political and economic developments influence the environment in which S&T policies must be considered is self-evident. The reverse — the recognition that technological change influences political and economic developments — is as obvious, but the nature of the effects of technological change are usually considered explicitly only in specific subjects or situations. There are some general observations about those effects, however, that deserve brief presentation; they form an important backdrop to an appreciation of the influence continued progress in science and technology will have on both S&T and on broader social and economic policies. In summary form, they include the following.

³ The relationship of science and technology to the evolution of the international political system will have a great deal to do with which future is likely to emerge. This subject is explored in my book: *The elusive transformation: science, technology and the evolution of international politics*. Princeton, N.J., Princeton University Press, 1993. See also Zacher, Mark W. The decaying pillars of the Westphalian temple: implications for international order and governance. In: Rosenau, James N. & Czempiel, Ernst-Otto (eds.). *Governance without government: order and change in world politics*. Cambridge, Cambridge University Press, 1992.

Broader opportunities, choice and flexibility

A key effect of advances in S&T is to offer a wider range of options for governments and industry to achieve specific goals. As one important result, R&D can increasingly be targeted on the design of technologies that will modify or undermine the basis for existing international economic relationships (e.g. natural resources dependencies).

Growing internationalization and globalization

As technology is developed that expands capabilities of size, distance, and power, it becomes increasingly international in its reach, either because it must be deployed in an international setting (e.g. space systems), or because its effects have unavoidable international impact (e.g. atomic weapons or communications technology), or because efficiencies of scale dictate international deployment (e.g. information networks). Growing international effects also result from the cumulative externalities of countless small decisions about uses of technology that cause consequences reaching beyond national borders, and increasingly to the planet itself. The emergence of an increasing number of global-scale issues, such as global warming or destruction of the ozone layer, both stemming from effluents of widely used and essential technologies, are obvious examples.

Increased need for international cooperation in R&D

A concomitant of the expanding reach of technology and its effects, along with the higher costs of equipment and research, is the increased requirement for international cooperation in the conduct of R&D. Research costs increasingly are higher than nations, even wealthy ones, can manage alone; international problems require multinational cooperation to understand causes and ameliorative measures; and development of mitigation technologies often require bringing to bear resources and competence beyond what one nation can do alone.

Inertia of large technological systems

As capabilities of technology expand, it becomes possible and efficient, often necessary, to link technologies in steadily larger systems that are now increasingly international in scope. Once the systems are in place, however, the sunk costs and fixed installations tend to reduce flexibility since change can only come slowly and at substantial cost. The global energy system, now so wedded to fossil fuels, provides an apt illustration of a massive system with major environmental implications that can be altered only gradually over many years.

Interlocking of societies and of economies

The result of expanding technological systems and internationalization of technology is to increase transnational interactions and to make economically attractive the development of multinational institutions, both serving to integrate national economies and societies. This is one of the most widely-remarked international consequences of technological change, commonly called interdependence. Examples are endless, as is the rhetoric.

Alteration of factor endowments

Technological change, occurring both in new systems and in the evolution of existing technologies, means that the factor inputs that determine, *inter alia*, the costs of manufacturing processes, or the demand for raw materials and energy, will be correspondingly changing. Indeed, one of the characteristics of continued technological development is to bring down, often dramatically, the costs of the inputs required for a particular function, as R&D leads to expanded output per unit of input. Technological advance that alters factor costs is not a new phenomenon, but the continuousness and breadth of change in technology introduces a fluidity to factor costs, and hence factor endowments, that in turn means rapid and continuing change in the economic potential of States and in their comparative advantage in the international trading system.

Diffusion of physical power and capability

The certain spread of knowledge and capability to package physical power in small volumes, with large yields, able to be delivered with high accuracy at a distance, at low effective cost, represents a development that makes all but inevitable the diffusion of physical power to nations, to insurgents, to groups, or even to individuals. Physical power need not only imply military applications: the ability of nations or corporations or rogue groups to perform (or misperform) activities on a scale that has direct effects on other nations, or on global conditions, is also growing. Deforestation of tropical rain forests, continued operation of poorly designed and maintained nuclear power plants, introduction of computer viruses that can be written by a single programmer and can lead to malfunction of large international systems, or the plans (now suspended) for reversing the flow of Arctic rivers in the Soviet Union, all illustrate the phenomenon.

Increased science-dependence of technology

The closer relation between the basic research laboratory and the commercial marketplace (in some fields) means, among other implications, that the

health of science and the results of fundamental research have greater significance for technological progress and economic competitiveness of nations than at any time in the past.

Increased complexity and uncertainty

Synergisms among technologies, increased sophistication of science and technology, and inevitable uncertainties in R&D processes mean that technological outcomes and their societal interactions are certain to be of growing complexity and to continue to be impossible to foresee in detail.

Discovering problems and causes

Specific outcomes from R&D may not be foreseeable in detail but, ironically, powerful new analytical methodologies for probing complex issues, growing ability to construct complex models to forecast future conditions, and improvement in technologies for measurement and computation will create their own problems for public policy. The use of these capabilities will result in finding problems the world did not know it had, will increasingly challenge desirable goals by detailing undesirable consequences of attempting to achieve those goals, will raise the need for potentially costly measures to deal with long-range phenomena not yet physically observable in daily life, and will complicate public issues with disturbing conclusions, the details of which are accessible only to experts.

Change made permanent

Governments and industry in this century have institutionalized a capacity for continued innovation which guarantees that the future technological environment, and thus the social environment, will never be static. New capabilities, new opportunities, altered competitive balances, unexpected problems, full-blown surprises will continue to lead to changes in the structure of societies and of issues, not least international affairs.

Increased significance of science and technology

Finally, it is worth recording the obvious, that the manifold interactions of science and technology with the social system have had the effect of increasing their importance in the functioning of society, and in the policy processes concerned with their governance. Science and technology have become part of almost all issues of social affairs, sometimes only a minor part, sometimes of central importance. They are now significant factors relevant to the making of

policy in many areas of national interest, including particularly economic and foreign policy.

All of these general effects of R&D are taking place in a world in which competence in science and technology is growing and diffusing on a worldwide basis. No longer is one nation, the United States, dominating S&T as it has since World War II. Notwithstanding its larger commitment of resources for R&D, there is much greater equivalence of capability today, shared by many countries. The United States may have the broadest general competence, but it is no longer the case that leadership in any given field will be found in that country. This is particularly relevant as esoteric defense technologies lose their significance, and as commercial technologies have in general become more advanced than those developed in a military context.⁴

This new world situation has significant repercussions in economic affairs, especially in trade relationships, and puts a premium on viable national policies for S&T, for promotion of effective international transfer of technology and for measures to move knowledge rapidly and profitably from the laboratory to the commercial marketplace. It is to those that we now turn.

2. Implications for S&T policies in the United States

The recognition that economic growth and competition must now have a central position in the setting of S&T policies may be widespread, but that is a far cry from leading to agreement as to what those policies should be. In fact, the nature of the desired policies are controversial in most countries, not the least in the United States.

There are many dimensions to these controversies, several of which bear directly on the question of how nations manage their scientific and technological enterprises in this new, interdependent, post-cold-war world.

Economic returns to R&D

One deceptively straightforward question relates to the economic returns to be expected from investment in R&D, and particularly from the resources committed to basic science. Presumably, if economic payoff is the intention, an economic return on investment should be anticipated, so that a reasonable cost-benefit analysis can be made and alternative expenditures compared.

But, the return on investment in research is peculiarly difficult to measure, so that much of the claim of economic benefit is made through qualitative, rather

⁴ Alic, John A. et al. *Beyond spinoff: military and commercial technology in a changing world*. Boston, Harvard Business School Press, 1992. p. 73.

than quantitative arguments.⁵ Even if estimation of the return on investment is possible for overall R&D (the best attempts at evaluation indicate social rates of return in excess of 50 per cent), it is not possible in advance to quantify the economic payoff of specific research endeavors.⁶

Thus, the very basis of support for R&D, when economic benefit is the primary criterion, cannot be pinned down and is open to dispute. Even when there is rough agreement on the amount that should be invested by government, the specific allocations among different fields, and among basic science, applied science, and development, are inevitably subject to personal judgment, bureaucratic competition, vagaries of the budgetary and policy processes, and lobbying from interested parties. Some nations formulate and implement their science policies in the face of these uncertainties with considerable aplomb and apparent clarity of view; others exhibit serious difficulties as they try to face an inherently complex situation with policy processes that discourage development of a coherent overall perspective. The United States is too often an exemplar of the latter.

Notwithstanding this rather fundamental difficulty in determining the economically appropriate allocation of resources, the United States Government has continued to increase overall funds for R&D at least equal to or ahead of inflation, until this current 1993 fiscal year.⁷ Disagreements arise within the overall allocations, with "small" science in traditional fundamental fields of physics and chemistry suffering relative reductions, while big science spectacles (space station, superconducting supercollider, human genome) continue to grow.⁸ And defense-related appropriations remain in excess of 60 per cent of the total federal R&D budget, only modestly reflecting in President Bush's budget proposal the changed security threat.

⁵ An excellent detailed summary of economic theory on the subject and of the primary writings and issues is given in A background review of the relationships between technological innovation and the economy: In: *Technology, trade, and the U.S. economy*. Washington, D.C., National Academy of Sciences, 1978. pp. 18-48. (Report of a workshop held at Woods Hole, MA, Aug. 22-31, 1976.) An Office of Technology Assessment study: Research funding as an investment, Science Policy Study Background Report n° 12, House Committee on Science and Technology, 1986, summarizes the state of knowledge of the returns to R&D investment up to the time of publication.

⁶ Mansfield, Edwin. Estimates of the social returns from research and development. In: Meredith, Margaret O.; Nelson, Stephen D. & Teich, Albert H. (eds.). *AAAS science and technology policy yearbook 1991*. Committee on Science, Engineering, and Public Policy. Washington, D.C., American Association for the Advancement of Science, 1991. pp. 314-15.

⁷ Marshall, Eliot & Hamilton, David P. R&D budget collides with the deficit. *Science*, 258: 208-9, Oct. 9, 1992. Note that these allocations were decided in the last Congress; the Clinton administration will seek to change them; the new FY 1994 budget will be released April 5, 1993 though some elements have already been publicly forecast (see later in text).

⁸ Ibid., p. 209. The Clinton administration has decided to continue both the space station and the superconducting supercollider, though with changes that are intended to reduce their costs in later years (Browne, Malcolm W. Clinton backs funds for science projects. *New York Times*, Feb. 23, 1993. p. C2). However, there is reason to believe these programs could prove to be vulnerable in the actual budget debates later this year.

The continued overall federal support for S&T in the face of growing budgetary problems and uncertainty of economic return can be attributed to several factors. The most important is simply the deeply-held conviction, established during and after World War II, that support for science and technology will eventually provide benefits that more than repay their cost, either in the private consumer marketplace or in public goods such as superior weapons, improved medical care, or higher agriculture productivity. The technological strength of the United States in the Cold War competition, and the astonishing blossoming of consumer technology that greatly enhanced the American standard of living, seemed to demonstrate beyond question the validity of the conviction. President Reagan, in a rather perverted testimonial to that sense that technology can bring any benefits asked of it, introduced the Strategic Defense Initiative in 1983 that envisioned a wholly unrealistic impermeable barrier against ballistic missiles.

Other more prosaic factors are also responsible for the generally unwavering support for S&T. Federal R&D expenditures on the order now of US\$75 billion, even though only 5 per cent of the federal budget, have developed significant political support in the districts in which the funds are spent. In addition, the fact that upwards of 2/3 of government R&D funds in the postwar period were justified on security grounds meant that challenges to those expenditures were not likely to have much success. And, the nature of the budgetary process in governments (powerful inertia to continue programs once they are in place, a particularly virulent characteristic of the United States budgetary process) makes it difficult to introduce sudden changes — especially reductions — in any specific category of expenditures.

From the general perspective of R&D resource allocation, what changes might be expected in the future? Certainly, the challenges to continued growth of R&D funding are likely to become more severe, for several reasons. One is the much greater consciousness today of the negative effects of technological change that result from unanticipated externalities and the mixed costs and benefits of the societal changes that accompany the introduction of new technologies. Coupled with recent exposure of apparent misbehavior of scientists and universities with regard to scientific norms of behavior and to the use of public funds, the general public attitude is likely to be more skeptical of the presumed benefits that R&D will bring.

The reduction in overall resources for defense will add to this negative pressure on R&D funding. The argument that defense R&D should be protected, even increased, as a hedge against the future while hardware purchases and troop levels are cut back may make excellent sense, but is not likely to be successful in political terms. Almost certainly, defense-related R&D will be reduced, though quite likely proportionally rather less than other aspects of the military effort.

On the other side of the coin, the importance of economic goals, especially as enunciated by the incoming administration, will serve to support increased budgets in R&D areas perceived to be relevant to those goals (as discussed

below). But this will mean, whatever the rhetoric, greater pressure to reduce the support for undirected basic research as funding agencies and Congress push for the primacy of economic goals.⁹

A recent disturbing trend is the falloff in what had been the steady increase in industrial R&D. Presumably a result of the recession and of a changing view of the value to the individual firm of support of basic research in central research facilities, R&D support in industry, except pharmaceuticals, will be flat or possibly fall in 1993.¹⁰ This development may indicate a changed perspective on the part of industry of the economic value of basic research to the firm, and a general drift in the private sector toward support of research only when the economic benefits can be forecast with considerable clarity. At the moment, the possibility of a permanent change in industrial attitudes toward support of research is speculation only, but current trends do show the significance of economic payoff as the dominant motive in the climate in the United States for support of research.

International competitiveness and R&D

The economic competitiveness issue that has come to dominate the formulation of United States policies for the support of R&D is played out in the arena of international trade in goods and services. The rules of the game may be controversial and in flux, but the central concept of a liberal trading system has been that each trading nation will use its comparative advantage to export what it can produce at lower cost than others and import products and materials for which others have a comparative advantage. When working properly, all nations benefit from what should be a positive-sum game.

Perhaps the most significant change that has taken place in the underlying principles of a liberal trading system, and one that relates directly to S&T, is the evolution in the determinants of comparative advantage. In traditional economic theory, the sources of comparative advantage are the relative endowments of a nation in the factors of production: natural resources, agricultural land, labor, and capital. Now, comparative advantage, or what many analysts would call competitive advantage, lies in a broader set of characteristics that prominently includes an economy's capacity for technological innovation to improve productivity. As a result, comparative or competitive advantage can be "created"; that is, it is a product of what an economy can produce through its human skills, its organiza-

⁹ Heads of basic research agencies, Congressional leaders, the National Science Board, and the President's Council of Advisors on Science and Technology in the previous administration all indicated movement in this direction (In science policy, too "it's the economy, stupid". *Science and Government Report*, Jan. 15, 1993, pp. 5-6).

¹⁰ Swinbanks, David. Recession grips industrial R&D. *Nature*, 361: 5-6, Jan. 7, 1993. A quarter of permanent industrial companies in a survey reported in this article plan to cut R&D budgets; 36 per cent said they would spend less on equipment and facilities.

tion, and the competence and productivity of its scientific and technological base. It stems, in other words, from national policy and corporate decisions, rather than from natural endowment.¹¹ Though not a wholly new idea — some aspects of comparative advantage were always derived from a nation's ability to improve its human and capital resources — its emergence as a major factor does alter appreciably one of the standard measures of a nation's international status and position, and places a premium on the quality and effectiveness of domestic policies, including in particular its policies toward science and technology.

Trade in high-technology products constitutes a growing share of the trade in manufactured goods: from 1966-86, technology-intensive goods grew from 14 to 22 per cent of world manufactured exports, reaching 42 per cent of United States manufactured exports and more than 33 per cent of Japan's in 1987.¹² In 1988, Japan and Germany had significant favorable high-technology trade balances, while the United States had slipped to a negative balance (exports/imports of 86 per cent).¹³ The United States position improved somewhat by 1990, though it is not clear whether this will be a continuing trend.¹⁴

The result is that the competitive position in high technology of industrialized countries has changed greatly from what it was in the sixties. United States technological leadership has been challenged by Japan as the latter has become a major exporter of high technology products, reaping substantial economic gains in the process. Europe has yet to alter its position appreciably, or to show what its capabilities may be, particularly in the post-1992 market. The United States remains the overall technological leader, but has been overtaken in many economically-important technological areas.

This new competitive situation has led to considerable soul-searching in the United States (as in other nations) as it seeks to find the appropriate policies to improve its technological performance, and hence its competitive advantage. A major difficulty is that though the importance of improving the technological position may be clear, how to do it — especially in an economy apparently losing its competitive edge — is not. Proposed measures are controversial because they involve political and economic interests that go far beyond technological matters alone.

¹¹ Porter, Michael E. The competitive advantage of nations. *Harvard Business Review*, Mar./Apr. 1990, p. 78; Tyson, Laura D'Andrea. *Who's bashing whom? Trade conflict in high-technology industries*. Washington, D.C., Institute for International Economics, 1992, Chap. 2.

¹² Quoted in Tyson, Op. cit., chap. 2.

¹³ OECD. *OECD in figures: supplement to the OECD Observer*, 170: 56-7, June/July 1991.

¹⁴ OECD. *OECD in figures: supplement to the OECD Observer*, 176: 56-7, June/July 1992. Data for various high-technology industries are given in: National Science Board. *The competitive strength of U.S. industrial science and technology: strategic issues*. Washington, D.C., National Science Foundation, 1992. NSB-92-138.

The debate in the United States has tended to focus on the extent to which the government should intervene in the economy, and in particular whether it should select commercially-important technological fields for special support. The issue is usually couched in the context of "industrial policy", with strident views that touch on deeply-held ideological, economic or political convictions.¹⁵ Some would support the general position that government should not intervene directly in industry, but should help in creating the essential education and competitive home environment that will spawn creative, innovative companies.¹⁶ In this view, companies are basically national in orientation, whatever the level of their international activities and ties, and are crucially dependent on their home environment and particularly on the internal vigor and competitiveness of that environment. Others call for an industrial policy that would involve varying degrees of intervention in the economy, adopting special measures targeted to improve the technological performance of economically-significant high-technology industries.¹⁷

Proponents of what has come to be called strategic trade theory argue that there are "strategic" sectors in an economy, high technology being a prominent example, that receive a higher return to investment or generate social benefits for a society that are not reflected in the prices paid to producers. Thus, contrary to the traditional assumption of free-market economists that market prices are the sole appropriate guide to the allocation of resources, the positive externalities of those strategic sectors for society as a whole would justify biases in government policy in their favor. Paul Krugman sums up the argument with regard to high-technology industry:

"Because of the important roles now being given to economies of scale, advantages of experience, and innovation as explanations of trading patterns, it seems more likely that rent will not be fully competed away — that is, that labor or capital will sometimes earn significantly higher returns in some industries than others. Because of the increased role of technological competition, it has become more plausible to argue that certain sectors yield important external economies, so producers are not in fact paid the full social value of their production.

What all this means is that the extreme pro-free-trade position — that markets work so well that they cannot be improved on — has become untenable. In

¹⁵ Even the relatively interventionist Clinton administration has avoided using the term "industrial policy" (see later).

¹⁶ Porter. Op. cit.; When the State picks winners. *The Economist*, Jan. 9, 1993. pp. 13-14.

¹⁷ Competitiveness Policy Council. *Building a competitive America — First Annual Report to the President & Congress*. Washington, D.C., Competitive Policy Council, Mar. 1, 1992; Johnson, Chalmers (ed.). *The industrial policy debate*. San Francisco, Institute for Contemporary Studies Press, 1984; Adams, F. Gerard & Klein, Lawrence R. (eds.). *Industrial policies for growth and competitiveness*. Lexington, MA, Lexington Books, 1983.

this sense the new approaches to international trade provide a potential rationale for a turn (...) toward a more activist trade policy."¹⁸

It may be reasonable to accept the idea of such strategic sectors, but as Krugman notes, that does not mean it is either easy or obvious how those sectors can be identified, or what policies ought then to be followed. Michael Porter argues that it is more important in any case for governments to follow policies that support incentives, effort and competition in industry, not subsidies or protection.¹⁹ In fact, national governments have for long been providing explicit or implicit support of one kind or the other for their high-technology industries, and continue to do so. Whether it be direct government intervention in Japan, or indirect support through defense R&D in the United States, governments have been involved.

It is worth noting that, alone among advanced technological nations, the United States has been unwilling to adopt comprehensive industrial policies until now. Notwithstanding the extensive support in the United States for basic science and for large-scale R&D to serve the public objectives of defense, space, agriculture, and public health, the United States government has not been willing to make a substantial commitment to use public funds to advance commercial technologies, though even the Bush administration had been quietly moving in that direction. Other advanced industrial nations that are the chief competitors of the United States, notably Japan and Germany, have been quite willing to embrace commercially-oriented S&T policies, providing support for development of commercial technology, for the diffusion of technology, and for strengthening industrial capacity to absorb technological information.

The United States policy response to date

The opposition in the United States to comprehensive "industrial" policies has not meant that there have been no policy innovations relevant to technological development for economic purposes. Various programs have been introduced in many administrations, and for long the commitments to defense and space R&D were assumed to be significant contributors to commercial technologies.²⁰ More attention has been given to technology policy in recent years, with the Carter administration introducing several important policy departures, and the Reagan and Bush administrations, both ideologically opposed to intervention in the marketplace, also adding significant new measures. Some of the latter were the result of Congressional action, some were launched slowly and reluctantly,

¹⁸ Krugman. *Strategic trade policy*. p. 15.

¹⁹ Porter. Op. cit. p. 30.

²⁰ Whatever the value of "spillover" in the past, there is now general acceptance of the view that it is no longer a substitute for civilian commitments to R&D (Alic, John A. et al. Op. cit.).

some are the product of legislation only in 1992, but the cupboard resulting from the last decade is not bare. These new policies put in place since 1980 deserve mention, for many of the Clinton administration proposals build on those legislative and program innovations, and form the legal and programmatic base actually in place at the time of writing. A sampling of these policies include:

1. Programs were instituted to endeavor to make the competence of the National Laboratories relevant to the civilian marketplace. There are 726 of these laboratories that receive roughly 1/4 of the total United States R&D budget (some US\$22 billion in FY 1991), the largest being the atomic energy weapons laboratories now in the Department of Energy, the laboratories of the National Aeronautics and Space Administration, the in-house facilities of the National Institutes of Health, and a variety of large Defense Department laboratories.²¹ By legislation in 1986, extended in 1989 to include contractor-operated laboratories, provision was made for cooperative agreements between them and industry for joint development of promising technologies developed in the laboratories that might be suitable for commercial exploitation.²² These agreements, dubbed Cradas, have begun to be implemented, and are growing rapidly in number (an exact count is not available, but they now number in the thousands).

2. Changes in patent policy were legislated in 1980 and 1984 to allow non-profit institutions, including the universities, to take title to patents derived from government-sponsored research.²³ By allowing ownership of patents, it was hoped that those institutions would have greater financial incentives to license the patents for productive use. This policy appears to be succeeding in stimulating greater patent and licensing activity, at least in some institutions.²⁴

3. The National Institute of Standards and Technology (Nist, formerly the National Bureau of Standards) in the Department of Commerce was authorized in 1988 to launch several new activities: an Advanced Technology Program (ATP) to provide public funds in response to industrial proposals to develop technological ideas to the pre-competitive stage; "industrial extension" programs, modelled after agriculture extension stations; and manufacturing technology centers to spur attention to this neglected subject in United States industry and universities. All of these are presently small in size, but capable of growth; Nist's overall budget

²¹ Council on Competitiveness. *Industry as a customer of the federal laboratories*. Washington, D.C. (no date).

²² Alic, John A. et al. Op. cit. pp. 79-80.

²³ Bayh-Dole Patent and Trademark Laws (PL 96-517).

²⁴ Skolnikoff, Eugene et al. *The international relationships of MIT in a technologically-competitive world*. Faculty Study Group, MIT, Cambridge, MA, May 1, 1991.

was increased 55 per cent in the last Congress to US\$384 million.²⁵ The Clinton administration intends to build heavily on Nist, as is detailed in the next section.

4. Antitrust legislation was modified to make possible industrial R&D consortia without fear of prosecution and threat of punitive damage awards. The result has been the growth of many industry programs of cooperation on generic or pre-competitive technologies — over 100 such consortia by 1992.²⁶ In addition, the Department of Defense has provided US\$100 million per year, the other half of a US\$200 million budget coming from industry, for the largest of these — Sematech — which is concerned with advancing the manufacturing process for semiconductors.²⁷ Sematech is generally considered to be successful (though the basis for that judgment is not clear); the others are too new to know the results.

5. The National Science Foundation (NSF) has instituted several programs, such as the creation of manufacturing research centers at universities, designed to stimulate scholarly research on manufacturing processes and to assist industry in giving greater attention to that phase of commercialization of technology. In addition, NSF is singling out four fields of "strategic" research for special R&D support: manufacturing, advanced materials and processing, biotechnology, and high-performance computing and communications.²⁸ These latter programs create some controversy in the scientific community since they compete within NSF for funds that might otherwise go for basic research.

6. The concern about so-called critical technologies has led the Congress, with reluctant agreement of the Bush administration, to establish a Critical Technologies Institute (CTI) to report to the Office of Science and Technology Policy (OSTP) in the White House with funding from NSF.²⁹ The actual role of CTI is not clear, except that it is supposed to identify those essential technologies in which the United States is weak, and propose measures to improve the situation. More likely, it will be used as an analytical staff arm by OSTP. The Rand Corporation has been awarded the contract to establish the CTI, which if it lasts

²⁵ Nist; Firing up U.S. industry. *Science*, 259: 19, Jan. 1, 1993; *Technology and economic performance: organizing the executive branch for a stronger national technological base*. A report of the Carnegie Commission on Science, Technology, and Government. New York, Carnegie Commission, Sept. 1991.

²⁶ Schacht, Wendy. *Cooperative R&D: federal efforts to promote industrial competitiveness*. CRS Issue Brief, Congressional Research Service, Library of Congress, Washington, D.C., Sept. 24, 1990.

²⁷ General Accounting Office. *Federal research: Sematech's technological progress and proposed R&D program*. GAO/RCED-92-223BR, Washington, D.C., July 1992.

²⁸ Anderson, Christopher. Strategic research wins the day. *Science*, 259: 21, Jan. 1, 1993.

²⁹ The Critical Technologies Institute. *Informing technology policy for the twenty-first century*. Washington, D.C., Critical Technologies Institute, Feb. 1993.

will become a novel "think-tank" arrangement at the level of the Presidency. There are many reasons to believe such an arrangement at the pinnacle of government is politically precarious and will not survive over the long term.

7. In the Defense Department there are several existing and new programs related to economic objectives. The most prominent of the existing programs is embodied in Darpa (Defense Advanced Research Projects Agency), a widely acclaimed advanced technology-development agency. Operating with a US\$1.4 billion budget, it has been responsible for spurring the development of technologies important for defense that also had important commercial impact; computers are the most notable example. Limited to subjects with military interest, Darpa has in recent years consciously worked on technologies with "dual-use" character. Its success has led to proposals either to broaden its charter to include development of commercial technologies, or to copy it in a new civilian-oriented agency outside the Defense Department.

More recent programs in the Defense Department cover a wide gamut. The 1993 Authorization and Appropriations bills, for example, include the following:

- Establishment of regional (in the United States) technology alliances to promote application of dual-use technologies in which there are regional clusters of strength.
- Provision for defense manufacturing extension programs to support existing manufacturing extension programs on a cost-shared basis.
- Establishment of a program to assist defense-dependent companies to acquire commercial-oriented capabilities, a major goal in the conversion from defense to commercially-oriented industry.
- Development of dual-use critical technology partnerships with industry to be administered by Darpa.
- Encouragement of commercial-military partnerships to foster development of commercial technologies likely to be needed in the future by the military.
- Establishment of advanced manufacturing partnerships with industry to improve manufacturing technology.
- Provision of assistance to universities, in cooperation with NSF, to develop manufacturing education programs.³⁰

³⁰ Senator Jeff Bingaman, chairman, Subcommittee on Defense Industry and Technology Committee on Armed Services, Press Release, Oct. 8, 1992.

All of these and some related programs amount to a shift of some US\$1.4 billion of defense R&D funding toward programs designed to transfer defense-oriented capabilities to the commercial marketplace. The majority are new efforts that will require implementation by the incoming administration.

Policy changes proposed by the Clinton administration

On February 22, 1993, President Clinton announced the substance of his proposals for a new technology policy.³¹ They are comprehensive in nature, but short on details or, in some cases, on budgetary implications. It is likely that most of the proposals will be enacted in some form, especially since many involve expansion of activities already in place. Caution is necessary, however, for the programs will be debated in a politicized climate that could substantially alter budgetary totals and the specifics of programs. In fact, the political dynamics are so askew that a kind of reverse feeding frenzy has developed as Congressional committees compete to outdo the president in spending reductions.³² These cuts will be reexamined when the budget details are considered later in the session, but if larger cuts are voted, they will inevitably reduce the size of the new programs proposed by the president.

Several general comments need to be made, aside from the nature of the political and budgetary process this year. The first is that technology policies will inevitably be subsumed under broader economic policy interests and results. For example, the export performance of the United States economy, especially *vis-à-vis* Japan, will directly affect the scale of resources devoted to technology programs, the steps taken to shield technological industries from foreign competition, and the attitudes toward sharing of information with foreign corporations. In addition, non-technological economic developments such as the movement of long-term interest rates will be a key determinant of the actual scale of technology policies that are seen to be required, and the extent to which those policies depart from past assumptions about the role of government.

Second, the Clinton administration in proposing these policies appears to be generally intent not only to reverse the long-standing *laissez-faire* view of government's role in the economy, but also to repair the traditional adversarial relations between business and government that have been so costly to the United States in international economic competition. The rhetoric of the proposals makes clear that the administration believes government has an impor-

³¹ President William J. Clinton and Vice-president Albert Gore, Jr. Technology for America's economic growth: a new direction to build economic strength. White House Press Release, Feb. 22, 1993. The specific material that follows is drawn from this document, except when noted.

³² Wines, Michael. Clinton bows to political inevitability, trimming \$55 billion more spending. *New York Times*, Mar. 9, 1993. p. A15.

tant role, but it is a role in partnership with industry, and industry must take the lead in selecting which are the important technologies. How this rhetoric will be carried out in practice remains a question, though some of the important appointments (Robert Reich at Labor and Laura Tyson at The Council of Economic Advisors in particular) have a prior commitment to these general ideas.

Third, there is a commitment to carrying out the technology policies on the basis of merit-based allocation of resources with the intent to avoid, to the extent possible, the political distribution of spoils commonly referred to as pork barrel expenditures. There is considerable skepticism about whether this will ultimately be possible in the American system in a time of recession, deficits, and the absence of a major security threat. The growth of Congressional "earmarking" in the distribution of funds for science facilities, is not an encouraging sign in this regard.³³

Fourth, an explicit commitment is made to basic science, "the foundation on which all technology policy is ultimately built". There is no doubt of the sincerity of this commitment but, as noted earlier, the pressures on the level of support for basic science may in fact inhibit fulfillment of the pledge over time.

With these comments, the key elements of the Clinton proposals can be presented. The proposed programs (only the highlights) will be grouped and summarized according to the administration's outline, and where relevant tied to existing programs.

Industry-government cooperation and support for commercial R&D

— A commitment to reduce the defense portion of R&D funding to less than 50 per cent of the total by 1998.

— Expansion of the Advanced Technology Program (ATP) of Nist in the Department of Commerce that provides funds for cooperative development of pre-competitive technology with industry. There would be a large expansion of the ATP budget, US\$103 million added to the US\$68 million in the current year, to US\$758 million by 1997.³⁴ Nist itself would go from US\$381 million to US\$1.37 billion by 1997, with the implication that Nist would become the chief civilian agency for implementation of technology policy.³⁵

³³ Norman, Colin. Brown turns up the heat on pork. *Science*, 259: 117, Feb. 19, 1993.

³⁴ Budgets, except where noted, come from a Feb. 16, 1993 White House public release.

³⁵ Andrews, Edmund L. Clinton's technology plan would redirect billions from military research. *New York Times*, Feb. 24, 1993. p. A14.

— Rename and redirect Darpa to emphasize dual-use technology development. The new name would be Arpa, with the D (defense) dropped, though it would remain in the Defense Department. This is in contrast to campaign documents that called for a "civilian" Darpa.

— Manufacturing R&D will be emphasized by all agencies.

— National laboratory budgets in Departments of Defense and Energy and in Nasa will be examined with the goal of devoting 10-20 per cent, "where appropriate", to technology-development partnerships with industry. Cradas — cooperative agreements for development of commercial technology between the national labs and industrial firms — will be given greater support (US\$47 million in the current year). It is too early to evaluate results of the existing Cradas, though there is justification for skepticism that the culture of the national labs will allow for substantial transfer of knowledge from them to the civilian sector or for much successful cooperation between the labs and industry.³⁶ The threat of major budgetary cutbacks in the defense sector and the allocation of funds to be used only for cooperative purposes will act as powerful spurs, however.

— The current NSF budget will be increased by US\$207 million, representing a 14 per cent increase over FY 1992. More than half the increase will go to "strategic research" subjects previously chosen (advanced manufacturing, biotechnology, materials research, computing and communications, and global change research).³⁷

— New programs to improve productivity of energy use in industry, transportation and buildings, along with renewable energy emphasis, to be mounted by the Department of Energy.

— Technology policy machinery in the White House will be strengthened, particularly OSTP and the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET). The Council is chaired by the president's science advisor.

Commercialization

— Encouragement of regional technology alliances to emphasize regional clusters of strength. This idea apparently stems from the work of Harvard Professor

³⁶ Andrews, Edmund L. Swords to plowshares: the bureaucratic snags. *New York Times*, Feb. 16, 1993. p. D1.

³⁷ Browne. Clinton backs funds for science projects. *New York Times*, Feb. 23, 1993. p. C2.

Michael Porter who has argued that clusters of industries and universities able to interact on a face-to-face basis are more important for competitive strength than the globalization that presumably had eliminated the importance of geography in the conduct of business.³⁸

— Encouragement of “agile manufacturing” programs that allow complementary firms to work together in temporary programs to exploit fast-changing market opportunities.

Access and use

— Support for a national network of manufacturing extension centers.

— Other efforts to spread knowledge and training about manufacturing processes and management.

Business and investment environment

— Make permanent the research and experimentation tax credit, which is intended to encourage increased industrial funding of R&D.

— Extend antitrust modifications to allow joint production, not just joint research consortia among firms.

— Ensure that trade policy strengthens high-technology industry, specifically that industry have full access to overseas markets and effective protection of intellectual property rights (IPR). This is likely to be one of the more contentious issues over the coming years.

— In general, improve the financial environment to encourage increases in availability of capital, long-term investment, and investment in equipment.

— Examine regulatory policy to minimize cost and encourage investment.

Education and training

— A variety of programs to improve the teaching of mathematics, science and engineering at all levels.

³⁸ Morgan, Dan. Think locally, win globally. *Washington Post*, Mar. 5, 1993. p. H1.

— Promotion of manufacturing education.

— Establish software and communications standards for education and training.

Information highways

— Increased R&D on supercomputers, faster computer networks, and more sophisticated software, with equipment to be built by the private sector.

— Promote information infrastructure efforts by industry.

— Increase dissemination of federal information.

Transportation and other infrastructure

— Investments in highway and transportation systems (a “new generation of automobiles”), R&D on civil aviation technologies, prototype maglev and high-speed rail systems, and smart highways R&D.

Basic science, mathematics and engineering

— The goal is specified as “world leadership”, with commitments for continued strong support of basic research in universities and national laboratories, and support for space science (working with foreign partners) and for environmental research.

These represent the highlights of the programs presently announced, though others could appear. For example, there have been proposals to attempt to avoid what is seen by many as the major stumbling block to successful policies — the vulnerability of new spending programs to a pork barrel approach in the Congress. One of the more innovative proposals, mentioned with interest in another forum by the president, is for the creation of a quasi-public entity, a “Civilian Technology Corporation”, that would receive a one-time appropriation of US\$5 billion. It would fund projects in cooperation with industry, as in the ATP of Nist, but would (it is argued) be able to be insulated more successfully from parochial political pressures.³⁹

³⁹ The proposal was produced by a panel of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, chaired by Harold Brown (Brown, Harold & Wilson, John. A new mechanism to fund R&D. *Issues in Science and Technology*, Winter 1992/93. pp. 36-41).

Vice-president Gore has been given primary responsibility for implementation, with OSTP in that capacity effectively reporting to him (the science advisory role of OSTP, not completely separable and thus possibly leading to future problems, remains focused on the president).

Some of the proposed initiatives do not have substantial price tags; others would be quite costly, and would therefore run up against the problem of increasing spending in the face of the pressure for deficit reduction. What will survive, in what form, and at what scale is presently far from determinable. The overall subject of technology policy to support America's competitive position, however, is sure to be at or near the front of the domestic and international agendas for much of this administration.

General characteristics of recent and proposed policy initiatives

The policies already in place and those proposed are and would be substantial innovations from the past. Those initiated during the Bush administration would certainly not have been expected of a Republican administration at the beginning of the eighties, and the new proposals go much farther in spirit and resources. They reflect several general characteristics of considerable importance that deserve to be noted:

1. Many of the programs are focused on manufacturing technology in the conviction — a valid conviction — that both industry and academia in the United States have accorded low prestige, and hence little funding or talent, to the technological problems of high-quality manufacturing processes. This is in sharp contrast to America's major high-technology trading competitor, Japan.

2. Investment is a key word, intended to emphasize President Clinton's conviction that the United States has been suffering from inadequate attention to the long-term development of its scientific and technological skills and infrastructure. The payoffs of almost all the programs will be long-term, thus making the immediate problem of committing resources in the face of budget deficits particularly difficult.

3. Those programs dealing directly with technological development focus on so-called generic or pre-competitive technology, in the generally shared conviction that the government is never in a good position to pick technological winners and losers, and would be bound to do poorly if it tried to deal directly with a marketplace technology. There is ample historical evidence for this view (e.g. the commitment to the development of commercial nuclear power technology, the Kennedy administration efforts to spur technological development in traditional industries, the abortive efforts to build a supersonic transport), though the line between pre-competitive and market-ready technology is not always as clear as

the distinction implies. The result, however, is that emphasis is placed on "partnerships" and industry "leadership", rather than government choice of technologies. Nevertheless, this is a substantial change in spirit, accepting clearly the appropriateness of government intervention in the economy.

4. International competition is a central concern, which in turn implies that the programs will be particularly sensitive to trade issues such as reciprocity of access, effective IPR protection, and trade performance.

5. Many of the initiatives are based on the scientific and technological competence of the defense establishment of the United States, and represent a desire to reorient that competence toward economic objectives. The goal is laudable on its own, but also reflects political pressure from affected local and scientific communities anxious to see existing laboratories and facilities remain when the defense budget is reduced.

6. The defense orientation has two (at least) other effects: (a) it mandates attention to those subjects that can be portrayed as having a military, as well as commercial, use, hence the emphasis on "dual-use" technologies; and (b) it makes possible larger funding allocations simply because the defense budget is so large that programs measured in the tens of millions of dollars are barely noticeable, and "reallocation" in this way seems to be a less painful way of reducing defense budgets.

7. The programs, even if fully funded, will be of small size in relation to the magnitude of the task of influencing a US\$6 trillion economy. Size is by no means an adequate measure of significance, but it does raise the concern as to whether this or any administration is likely to be able to secure sufficient resources to make a genuine difference in the economy.

8. Finally, in typical United States fashion, the policy process results not in one or a few large programs, but a wide array of programs that represent many different views of what is needed, and that are being managed within many different government agencies. That may be an effective way to experiment to determine what works; it may also be a route for scattering of scarce resources across an array of sub-critical efforts. Time will tell.

Other elements affecting S&T policy

Altered content of trade-relevant issues

One of the direct consequences of the new appreciation of the determinants of a nation's competitive advantage in high-technology is a significant expansion

of issues relevant to trade negotiations; no longer can trade talks be confined to traditional matters such as tariffs, quotas, and direct export subsidies. National policies and practices in areas that previously received little attention in trade negotiations are now directly relevant. As David Mowery and Nathan Rosenberg observe: "Because of their effects on trade flows, domestic subsidies for R&D, government procurement, intellectual property regimes, investment subsidies, patent policies, regional development policies, and other policies that historically have received little scrutiny from trade policymakers are now central to trade negotiations".⁴⁰ Other subjects become relevant as well, such as the traditional relationships among business, government, scientific, and financial communities. In effect, the structural differences among nations become, in Laura Tyson's terms, a major element of trade conflict in technology-intensive industries.⁴¹

The result has been that a set of subtle and particularly difficult issues has become a necessary part of international trade negotiations. New rules, agreements, and perhaps new kinds of relationships that reach deeply into national styles and cultures will be necessary to maintain a "level playing field".⁴² Technological competitiveness has thus resulted in a trading system that now directly challenges national structures and styles, not just traditional trade issues.

Basic research, competition, dangers for the universities

It is relevant to S&T policy that in this new competitive context, basic science has become a more immediate factor in a nation's international position. The greater scientific content of some technologies means that basic research that might be related to commercially strategic fields comes closer than ever before to being an instrument of international competition. The result is growing pressure to limit the free dissemination of research results and to constrain the traditional openness of university laboratories where most basic research is performed in the United States.⁴³ Suddenly, principles of open communication, deemed by scientists to be fundamental to the progress and health of science, are jeopardized by the perceived relationship of science to the economic competitiveness of nations.

This may prove to be a divisive issue in the new administration, for the emphasis it is giving to the nation's competitive position in technology carries with it an overtone of "managed trade", and perhaps a degree of protectionism.

⁴⁰ Mowery, David C. & Rosenberg, Nathan. *Technology and the pursuit of economic growth*. New York, Cambridge University Press, 1989. p. 277.

⁴¹ Tyson. Op. cit., chap. 2.

⁴² Tyson. Managing trade conflict. p. 6; Bergston, C. Fred & Graham, Edward M. Globalization of industry and national governments. Washington, D.C., Institute of International Economics, 1992.

⁴³ An MIT faculty study analyzed the many issues involved in foreign access to American universities (Skolnikoff et al. Op. cit.).

President Bush was completely committed to a free trade position; President Clinton and Vice-president Gore argue the same, but on condition that a "level playing field" exists, which might be defined with regard to R&D as equal access to the products of research in each country.⁴⁴ If it is believed that the nation's competitors, and particularly Japan, have access to the open research at American universities without reciprocity, there could be attempts to restrict that access or to retaliate in some other way.

The issue at one level has a spurious simplicity: if research is supported by the State for the economic benefits it will bring, then it can be argued, and many do, that competitor nations or companies should not have equal access to the results of the research. Since most government-supported basic research in the United States is conducted in university laboratories and in other public research institutions, that view implies imposing some restrictions on access by foreign visitors and foreign students to those universities and institutions.

There would be several costs of taking such a step, a policy that is being seriously proposed by some in the United States.⁴⁵ One is a result of the spread of quality research and scientific and technological competence throughout the world. That means that to maintain frontier research in any subject, scientists must have access to information generated by scientists and laboratories wherever they may be located. Any restrictions are not only undesirable, but counter-productive; they would eventually erode the vitality of the scientific enterprise itself which it is hoped will be the source of new knowledge for industrial exploitation. It is the quality of a nation's S&T enterprise that is the key to its long-term value for the nation, and that quality can be served best by maintaining an open research enterprise that is fully integrated into the worldwide scientific community.

Moreover, it is not the timing of industry's access to new knowledge but the competence of a nation's industrial structure to translate the results of the laboratory into competitive products that is the primary key to the commercial exploitation of knowledge. The focus must be on improving the ability of industry to convert knowledge to product, rather than on damaging the sources of knowledge, a view that is echoed in the Clinton administration policy proposals.

The argument is easy to make at this level of generality. In practice, however, the issues become somewhat clouded because of asymmetries in the structure of the research enterprises in different countries. In the United States, the

⁴⁴ Bradsher, Keith. Split goal on trade. *New York Times*, Feb. 27, 1993. p. 6.

⁴⁵ *Is science for sale? Transferring technology from universities to foreign corporations*. Twenty-Eighth Report by the Committee on Government Operations, Oct. 16, 1992. Washington, D.C., U.S. Government Printing Office, 1992. Sen Shelby (D-Alabama) proposed on Feb. 17, 1993 a prohibition on the sharing of information from NSF or NIH-funded research with representatives of foreign corporations or their American subsidiaries before publication. He withdrew the proposal on the promise of hearings to be held on the subject within two months.

basic research conducted in universities and public institutions constitutes the majority of the basic research performed in the country. It is conducted with open access and rapid publication of results. In Japan, however, and in some other countries, relatively less basic research is performed overall, with industry dominating the research scene and the universities playing a much less significant role. Japanese industry follows the practice of industry in all countries of restricting the flow of information from their laboratories, so that reciprocity of access is difficult to realize in practice.

The Japanese have relied heavily on the results of basic research in the West, a dependency they have begun to correct by increasing the support for basic research at their universities. But given the existing situation, and Japan's success in high-technology trade, the apparent one-sided access of Japanese industrial visitors to research laboratories in the West not surprisingly arouses political reaction and strident calls for imposition of restrictions on access to those laboratories. There is particular concern in those fields, such as molecular biology, in which the time-lag between the laboratory and commercial exploitation appears to be particularly short.

The universities respond — though not as an organized group — that the problem is much exaggerated and is, in any case, primarily a problem of shortcomings of industry rather than of ease of access to knowledge; that there is more actual reciprocal exchange of knowledge with Japan than the asymmetrical structure of research establishments would imply; that effective transfer of technology is much more difficult than is assumed; and that, most importantly, the supposed cure (imposing restrictions) would be much more costly to economic competitiveness than the disease. Even if access to some of the more applied work at universities does assist foreign industries, so the argument is made, that knowledge is equally available to domestic industries, and there would be no way to apply restrictions only on commercially-relevant research without damaging the whole research enterprise.⁴⁶

Whatever the resolution, if there is ever "resolution", of this issue of unfettered access to basic research at the universities, the perceived economic relevance of university research will certainly increase the pressure for universities to be more attentive to the need for economic returns to R&D, and to devise ways to improve the effectiveness of knowledge transfer to American industry. Not surprisingly, this has raised concern among scientists, who believe using economic objectives to determine basic research objectives is not only undesirable from the perspective of science, but also doomed to failure. That is, that the most likely economic benefits will be achieved through the unexpected advances of knowledge and synergisms among fields, not by research toward specific economic applications, which will inevitably be limited in imagination.

⁴⁶ Skolnikoff et al. Op. cit.

Programs to stimulate more effective transfer of knowledge are, however, more acceptable at the universities, and many of the leading research institutions have taken advantage of the new patent arrangements to mount aggressive patent and licensing programs. Industrial liaison programs at universities are now common, though those that include foreign companies as members have run into the criticism of transferring knowledge too readily to foreign competitors. Universities have also responded to the importance of improving education and research in manufacturing technologies. Federal government support has helped, but industry itself recognizes the need and has provided considerable support for some programs at leading universities.⁴⁷ However, the general and growing pressure on realizing economic benefits of research at universities will undoubtedly lead to policies that will challenge some of the cherished principles of operation American universities believe to be essential both to their independence and to their productivity.

This challenge will also put into bolder relief a larger and in the long run a potentially more dangerous issue: the possible changes in national attitudes and policies toward science and the universities. In the United States there is a growing skepticism about science and technology, with the distinct possibility that the "social contract" between the government and the scientific community crafted during and after World War II may now be unravelling.⁴⁸ The combination of the end of the Cold War which removes the security need for large-scale funding and the justification for merit-based allocation of research funds, a continuing fragmentation of national politics that erodes central authority, a divisive new populism that is skeptical of the role of scientists and of elite universities, and a growing wariness of the externalities of technology could result in the United States in a wholly new approach to science that no longer accords it the privileged apolitical status in the policy process that it has enjoyed for so long.

Many scientists are seriously worried about this situation and its likely evolution, though it is not yet near a crisis stage. It is most likely, however, that the United States will at the least be undergoing a quite fundamental reevaluation of its basic science policies over the next few years, with the possibility of major restructuring to follow. President Clinton and Vice-president Gore appear to be

⁴⁷ The Leaders for Manufacturing Program at MIT may be the most ambitious. A joint program between the Schools of Management and Engineering, it is supported by 13 companies, and is training some 45 students per year to be able to work in the manufacturing sectors of American industry. Stitt, Judith V. Leaders for Manufacturing, with a "Big M". *MIT Management*, Fall 1992. pp. 2-30.

⁴⁸ There was no formal contract, but there was rough acceptance of the idea that government would provide unfettered support for science, to be divided following the norms of the scientific community, in return for which benefits would be realized both for the nation's security and its economy. Bush, Vannevar. *Science the endless frontier: a report to the president on a program for postwar scientific research*. Washington, D.C., NSF, 1945 (NSF 60-40) provided the underlying rationale for the relationship.

fully supportive of the traditional postwar norms of the government/science relationship, but the press of events, especially changes in the economic situation, may lead them to be less sympathetic.

Environment

The incoming administration enters office with a strong electoral commitment to the environment. That will have several consequences, but for this review, the major effects will be to increase environmentally-related R&D, and no doubt to increase regulations based on the results of that research.⁴⁹

The question that follows will be whether the nation's economy and its international competitive position will suffer from the commitment to more environmental technology and regulation. The evidence is in dispute. Vice-president Gore and others argue not only that there is no conflict between the economy and the environment, but that environmental technology can be a major contributor to economic health.⁵⁰ A contrary view sees environmental regulation as a cost to be carried by American products that foreign-made products are not assessed, while offering little in the way of direct technological opportunity.

The resolution of this controversy is not certain, though it is worth observing that the Japanese government has made a substantial commitment to the development of technologies to meet environmental regulations in the apparent belief that there will be a substantial market for such technologies.⁵¹ The Clinton administration is now proposing an increase of US\$272 million over four years for the Environmental Protection Agency to support private-industry development of environmental technology.⁵²

A substantial proposal for greater international focus on environmental research made by the Carnegie Commission on Science, Technology, and Government may have a good reception in Washington and has already aroused considerable international interest. The commission proposed creating an international Consultative Group for Research on Environment that would sponsor a network of environmental research centers, parallel in concept to the Interna-

⁴⁹ It is estimated that United States environmental regulations cost the economy approximately US\$120 billion in 1991 (Repetto, Robert & Dower, Roger C. Reconciling economic and environmental goals. *Issues in Science and Technology*, Winter 1992/93, p. 29).

⁵⁰ Ibid. pp. 28-35. A study at MIT showed that American states with more stringent environmental regulations were actually doing better economically than those with weaker regulations (Meyer, Stephen M. Environmentalism and economic prosperity: testing the environmental impact hypothesis. MIT Project on Environmental Politics and Policy, Oct. 1992).

⁵¹ Swinbanks, David. Going for green technology. *Nature*, 350: 266-7, Mar. 28, 1991.

⁵² Markoff, John. Clinton proposes changes in policy to aid technology. *New York Times*, Feb. 23, 1993, p. 1.

tional Agricultural Research Centers.⁵³ Such a network could be of great value both to industrial and developing countries in future attention to environmental problems. The ties between the Carnegie Commission and the new administration, and the similarity of interest on this subject, make it probable the proposal will receive favorable attention.

3. Implications for developing countries

There are many implications for Third World nations that can be drawn from the discussions above, stemming both from the developments to be expected in science and technology, and from the likely direction of United States S&T policies. This paper is not a suitable vehicle for laying out the policy choices developing countries ought to consider, but some of the more important implications deserve to be highlighted. In particular, the signal importance for developing countries, and especially for the larger newly industrializing countries (NICs), of building indigenous capacity in science and technology is the one overwhelming implication that emerges from almost all of the relationships and changes discussed in this paper.

The effects of continued advances in S&T

We saw, earlier in the discussion, a schematic exposition of the likely societal effects of continued development of science and technology. Many of those will have important implications for developing countries, requiring the ability to respond to those effects and, at least as important, the ability to participate appropriately in the international relationships that grow from them.

It was noted, for example, that the nature of new technologies makes necessary or stimulates the creation of large international technological systems. To be able to take part effectively in the design of the systems, which will often determine who will benefit most from them, and to take a measure of operational and policy responsibility, will require technological knowledge and capability on the same order of competence as the other participating nations. Knowledge will be a necessary prerequisite for ensuring receipt of a fair share of the benefits of the systems.

Similarly, the rising importance of global issues and the increased interaction and integration among economies, so much of it technologically based, mean that indigenous technological capability is essential in order to participate effectively and to the net advantage of the nation in the innumerable negotiations and

⁵³ Carnegie Commission on Science, Technology, and Government. *International environmental research and assessment: proposals for better organization and decision making*. New York, Carnegie Commission, July 1992.

relationships that arise. Competence is necessary to understand the issues, to determine where the national interest lies, and to negotiate successfully with other nations, many of whom will have larger scientific and technological communities. These global issues can enhance the bargaining power of Third World countries (since Third World country adherence will be essential to deal with many of them), but the issues must be thoroughly understood to capitalize sensibly on that power.

Other implications of technological change may reduce bargaining power, for example the growing ability to target R&D to produce technologies with specific desired characteristics that will allow scientifically advanced nations to design around resource or other dependencies.⁵⁴ This capability cannot be prevented, but anticipating its consequences and moderating its impact will require scientific and technological knowledge necessary for development of realistic policy options.

Closely related, the effects of technological change that alter factor costs of production may reduce the present advantages of Third World countries as sites for industrial production. The ability to compensate for such technological change, to create alternative incentives, even to determine just where the national interest lies, for example in judging the risks of lower environmental standards, similarly requires significant indigenous S&T competence.

And, quite obviously, the increasing science dependency of new technologies means that any nation hoping to be able to compete in world markets in technology must develop a science base adequate to support the rapid pace of technological evolution set by the technologically advanced countries.

Other examples could be drawn, but the overall implications for Third World nations are simple and rather clear:

1. The traditional comparative advantages of Third World countries in international trade are in general decreasing. That is, with the exception of fossil fuels, industrialized countries are less dependent on the resources or formerly favorable factors of production of those countries. (This, of course, says nothing directly about the markets those countries provide now or potentially.) Thus, the bargaining power of developing countries that is based on traditional comparative advantage is deteriorating.

2. The other side of that coin is that the growth of global-scale technologies and problems does serve to enhance the bargaining power of developing nations,

⁵⁴ Fossil fuel dependencies are the major exception, but only because of the scale of the energy industry and its fundamental nature for all economies. However, the potential is there to eventually reduce fossil fuel requirements through development of alternatives and improved efficiency; the time scale will be much longer, however, than for other resource dependencies.

especially the NICs and large, populous States whose participation is essential for dealing with the technologies or the problems.

3. Finally, and overwhelmingly, a competent indigenous capacity in science and technology is essential in order to participate in modern international technologies, to be able to negotiate effectively on increasingly complex international issues, to take advantage of enhanced bargaining leverage or to offset declining leverage, and to be competitive in high-technology trade.

These lessons may be simple to state, but, of course, achieving that competence in indigenous science and technology is not a simple matter.

Effects of future United States policies

The changes in United States S&T policies introduced during the Bush administration and the far-reaching proposals of the Clinton administration will necessarily have repercussions on developing countries; some of the more important effects that are relevant to S&T may come from other policy areas, however.

For example, one change in direction already accomplished by the new administration is the modification of United States policy toward international population planning programs. The former ban on United States contributions to international programs that include abortion counseling has been lifted by Executive Order of the president. This will certainly signal a more aggressive United States population policy in general, with a return to the policy stance of the Carter administration on this subject.

A more positive policy toward multilateral institutions can also be expected, with the needs and issues of those institutions put higher on the foreign policy agenda, especially for those involved in global-scale issues. The preliminary budget revisions pledged to make the United States "current in its legal obligations to multilateral institutions". However, it is not at all likely that greater interest will be accompanied by large increases in funds, either for the organizations or for their regulatory and technical assistance efforts. The scale of the American budget deficit, the problems of the domestic economy, and the inward-looking preoccupation of the American public preclude large increases in resources for foreign activities. If there is an exception, it will be for international security functions of multilateral organizations, which will take precedence over technical assistance or environmental roles; immediate security needs always crowd out longer-range goals with lower political visibility.

There may also be a move to review and change the basic foreign aid legislation, which has remained essentially the same since the Agency for International Development (AID) was created in the Kennedy administration. In fact, funding for AID has been "cut pending reorganization of that agency". If that is carried out, science and technology will probably be accorded a larger place in

the new structure, but there is little reason to expect a fundamental change along the lines of the proposed Institute for Scientific and Technological Cooperation (ISTC) that almost came into being under President Carter.⁵⁵ A recent report of the Carnegie Commission on Science, Technology, and Government called for a thorough revamping of the United States policy process for foreign aid, greater attention to United States private and public sector capabilities in S&T in efforts to assist development, and a general approach of creating partnerships (domestically and internationally) in aid of development.⁵⁶ It is too early to forecast what impact this report will have, but the subject is not likely to be accorded high priority in the Clinton administration.

It is also possible that the sheer scale of United States interactions with other countries and the concomitant difficulty in coordinating those activities through the Department of State or the White House will result in greater independence in the international operations of each government department. That is, there may be greater acceptance in the executive and legislative branches of the limitations and costs of coordination, and appreciation of the advantages of allowing the expertise of technical ministries to have more flexibility in their international activities. That is not the current tendency in the American policy process; in fact, there is more interest in tight coordination than decentralization of policy, but pressures of scale and need may force eventual movement in the direction of decentralization.

Large increases in direct resources for foreign aid are not at all likely for many years into the future, except in the most unlikely event that the United States was forced to such a move by a global issue that threatened catastrophe. The pressure of domestic economic problems and the continuing unpopularity of foreign aid in the American public, make substantial resource increases out of the question.

What may be possible, however, is the gradual development of alternative routes for the transfer of resources from North to South in the context of global problems. For example, funds for improving the efficiency of use of fossil fuels in order to reduce CO₂ emissions might be authorized to be spent by the appropriate government agency wherever they are most cost-effective. With that authorization, funds would more likely be actually spent outside the United States, not in the context of foreign aid, but to serve an environmental goal. Tradeable emission permits would also have that resource transfer characteristic that would bypass traditional foreign aid bureaucracies. The interest of the new

⁵⁵ Agency for International Development. FY 1981 Congressional Presentation, Institute for Scientific and Technological Cooperation. (Submitted as Annex IX of the Congressional Presentation of AID, 1980.)

⁵⁶ Carnegie Commission on Science, Technology, and Government. *Partnerships for global development: the clearing horizon*. New York, Carnegie Corporation, 1992.

administration in global environmental issues makes this development more likely in the next few years than would otherwise be the case.

With regard to the impact on developing countries of S&T policies themselves, the most significant effect of the increased focus on economic competitiveness is likely to be felt in a more aggressive trade stance. As noted, President Clinton has endorsed a free trade position, but it was accompanied by an insistence on reciprocity with regard to markets and on effective IPR protection. The United States has had many disputes with Third World countries about access to markets and IPR and those are likely to continue, perhaps grow. In general, policies with serious protectionist overtones are much more likely in the new administration than in the preceding Bush and Reagan years. Much of that new assertiveness will be directed at Japan and, to a lesser extent, Europe, but some will certainly affect developing countries.

This will be particularly so for those countries, like Brazil, that are striving to industrialize rapidly, and in the process may be following policies to which the United States objects, such as infant industry protection, large subsidies for specific industries, or demanding policies on intellectual property rights. Given the deeper determinants of competitive advantage today, the United States stance in international trade negotiations may prove to be both tougher and more concerned with "domestic" issues not previously a part of those negotiations.

There seem to be few other direct implications of United States S&T policies for developing countries, other than the general appreciation that if the policies are successful, the United States will be a more formidable technology competitor in the future, making it harder for newer entrants to compete. On the other hand, a more prosperous United States will be a more valuable trading partner, offering markets for developing country exports and an easier attitude on transfer of resources.

Successful policies in the education and training area could also have the effect of reducing the current need for foreign scientists and engineers to staff American universities and industry, thus possibly reducing the so-called "brain drain".⁵⁷ This cannot confidently be predicted, however, for the success of the education policies may be harder to achieve than any other aspect of the policy package, and in any case a thriving technological economy would be likely to attract even more students from abroad who elect to stay in the United States

Implications of Nafta and possible follow-ons

The S&T policy implications of Nafta and its possible later extensions follow from much of what has been covered above. The essential point is that what-

⁵⁷ National Academy of Engineering. *Foreign and foreign-born engineers in the U.S.* Washington, NAS, 1988. p. 3. National Research Council. *Summary Report 1989: doctorate recipients from U.S. universities*. Washington, NAS, 1990. p. 46.

ever benefits the agreement may accord to the developing countries of the Western Hemisphere that stem from increased low-cost and low-skill labor opportunities are likely to be fairly short-lived. Technological trends will gradually make those advantages less important, at least in high-technology production, as technological advance alters factors of production in favor of the more advanced industrial nations.

Similarly, apparent possibilities for creating pollution havens in poorer countries will also not last for long, as increased R&D on environmental matters and increased attention to environmental issues in the new administration will likely reduce the need or the incentive for relocating production from the United States. In any case, Nafta will probably not be approved by the new administration without parallel agreements on limiting the creation of environmental refuges.

Finally, the effort of the United States to improve its technological competitiveness against nations in Europe and the Far East, will unavoidably also put pressure on those aspiring nations in the Hemisphere that are trying to develop their own competitive skilled industries. It is clear, again, what a premium there is on the ability of the less-developed nations of the Hemisphere to build their indigenous competence in S&T as fast as they sensibly can do so.

4. Conclusion

The science and technology policies of the United States are clearly entering a new phase, not only because of the change in administration, but also because of the manifold changes in both domestic and international affairs, and because of developments in science and technology themselves. Economic issues have come to dominate the agenda, and that is reflected in substantial new attitudes toward the roles of S&T, with a host of new programs already underway that are likely to be substantially expanded and added to by the new president. The general thrust is likely to increase the role of the federal government in creating the necessary conditions for economic innovation. The intent is to develop partnerships with industry, though the extent of intervention by the government and the reliance on industrial leadership will be determined only as the policies are legislated and implemented.

Whether the S&T policies will be successful or not in improving the nation's competitive position is obviously not certain, but the extent of the changes proposed, and the new spirit in evidence, gives ground for optimism. In any case, the policies are likely to make the United States a more formidable trading partner against all but the most effective economies, which may mean only Japan for now, and thus a challenge to Third World countries aspiring to improve their technological position. The policies will undoubtedly also create some problems within the United States, especially with relation to the support for fundamental

science, and carry the danger of introducing protectionist strains in areas previously immune, for example, in university-based research.

With regard to developing countries, the single most important S&T-related need is to build indigenous capacity in science and technology that will allow them to participate adequately in the host of new technological, competitive, and environmental issues they will have to face in the near future. Some help for this may be provided by the industrialized countries, but the political environment, especially in the United States, remains unreceptive to devoting substantial increased resources in that direction. The need for developing country cooperation in international technological systems and on emerging global-scale environmental problems, however, may increase the bargaining power of those countries, forcing expanded movement of resources over time from the countries of the North to those of the South.

Overall, it can be said that the world is entering a new era in science and technology policy, as it confronts a host of new problems in almost every sphere of social and political affairs. The developments in the United States will not be unique, but the size of the United States economy will magnify the international impact of whatever changes that nation makes. The beginning of a new administration at this time with new ideas is appropriate; the results are far from assured, but the energy that has been shown and the initiatives proposed make the future brighter than it has been.

United States science and technology policy: issues for the nineties

Lewis M. Branscomb*

Preface

This analysis focuses on the science and technology issues as they relate to the changing political and economic environment in the United States. While this paper does not attempt to evaluate S&T policy issues in Brazil, the possible impacts of policy changes in the United States on Brazil are noted.

The paper does not deal in detail with a number of "science for policy" issues, such as health care, environmental preservation, defense technology, education, or the cultural value of science, even though these are very important issues in the United States at this time. A few words about each of these omissions is needed.

Health care, which is consuming over 14 per cent of GNP (2.5 times as much as defense) is not primarily a technology program (except perhaps for the costs of using the technology in a wasteful manner). The biotechnology industry has been the beneficiary of the extraordinary investments in "pathbreaking" research by the United States government, even though the National Institutes of Health (NIH) research investments were not justified by an economic objective. Only recently has NIH taken its economic role seriously.

The environment does indeed pose important technical issues, both domestically and internationally, and, like health care, has a major economic impact, through cost burdens on industry and governments alike. This is an area of great importance to Brazil, and in which Brazil has taken a strong international leadership position, for example by hosting the UnCED.

Defense technology is dealt with extensively in this paper, but not from the perspective of defense requirements as much as from the considerable impact of defense procurement and R&D activities in the economy and the expectation that much of the new civilian technology program proposed by President-elect Clinton will be paid for out of defense funding. The defense establishments in the United States and in Brazil continue to have a major role in technology, but with the rising importance of economic goals, the role of defense is diminishing in

both countries in comparison with private sector activity and government investments in industrially relevant technology.

Finally, this paper focuses on the health of universities because of their critical role in the S&T "food chain" and their contributions to technology diffusion. But it does not address the problems of education, either in the public schools or higher education, except in the context of the relationships of higher education to S&T and to the federal government. For a recent study of the federal government role in the reform of pre-college math and science education — a major issue facing the United States — see a recent study for the Carnegie Commission on Science, Technology and Government lead by the author: *In the national interest: the federal government in the reform of K-12 math and science education*. (Sept. 1991), and other material cited in the Annotated bibliography at the end of this paper.

The material in this paper was prepared by the author, but some sections have been taken from the author's unpublished work and from recent published work cited in the bibliography.

Lewis M. Branscomb
Cambridge, MA
January 3, 1993

* Albert Pratt Public Service professor; director, Science Technology and Public Policy Center for Science and International Affairs, Harvard University.

1. Introduction

This review of United States science and technology policy and discussion of current issues is made at a time of rapid change in United States policy. The election of President Clinton and Vice-president Gore brings a new generation to power in the United States federal government, the first persons elected to these offices since World War II who did not participate in that war. This is, perhaps, symbolic of a shift in American views of its role in the world. No longer are United States views colored by superpower competition with a nuclear-equipped and sometimes expansionist Soviet Union — a view that affected American attitudes toward not only the USSR and its NATO allies, but unallied and development countries as well. The end of Cold War, the rise of economic competition in an increasingly global economy, rapid change in the nature and power of science and engineering, leave the United States with a new political, economic, and security agenda but with most of the same institutional structures in its government that were built up during the Cold War. In addition many Cold War era concepts about the nature of technological innovation and the part science and engineering play in it, still dominate political thinking.

Thus many of the concepts and new policy initiatives that have appeared in the late eighties and early nineties are transitional in nature, and may well change. This is also true of the missions of government agencies (especially Defense and Commerce), the roles of national institutions (government laboratories, universities, consortia of firms), and — importantly — the role of state governments in the promotion of economic activity through investments in technology, in industrial extension services, and in human resources. This paper will identify the post-war origins of United States S&T policy and the institutions that drive it, will analyze the elements of policy that are in flux, and will focus in its conclusion on the issues likely to be most hotly debated in the Clinton administration's first year.

The boundaries that distinguish technology policy from economic and industrial policy are fuzzy at best. Technologies are created for economic reasons and the investments they call for must be economically justified. Technology is an important element of industrial success, but only one element, along with labor productivity, capital cost, and managerial skill. Technologies are almost never an end in themselves.¹ A technology is the aggregation of capabilities, facilities, skills, knowledge, and organization required to successfully create a useful service or product. Technology policy concerns the public means for nur-

¹ There are exceptions, perhaps, in the military sphere. Historians may conclude that the Strategic Defense Initiative of President Reagan, while never more than a technology — and a highly speculative one at that — had an important impact on Soviet perceptions of their ability to sustain the nuclear arms race, given the state of the Soviet economy. But the other example of a technology of enormous political consequence, the Apollo mission capability, illustrates that in the end only mission success counts.

turing of those capabilities and optimizing their applications in the service of national goals and the public interest.

United States S&T policy is, with exceptions noted below, largely uncoded; it must be deduced by observation of the laws, the organization of government, and the actions of government managers and agencies. That policy is continuously in flux, and it is unclear what direction the *de facto* policy will take in the next decade. But certain generalizations about the directions of policy change can be made with some confidence:

— The federal government will gradually shift its priorities away from defense and space and toward technology development to support industrial competitiveness.

— Private firms, in a weakened antitrust enforcement environment and responding to international competitive pressures and to changes in innovation processes, will move away from vertical integration in favor of alliances of many kinds with suppliers, distributors, and for pre-competitive and infrastructural R&D with competitors in consortia.

— Government decisions on civil technology activities will be increasingly shared with private sector bodies, and programs undertaken in evolving forms of public-private partnerships.

— Government technology policy will become increasingly well codified and will begin to shift from almost exclusive emphasis on generation of new technology to increased support for technology diffusion: accessing, adapting, and using technology.

— After a difficult and protracted period of downsizing, the defense effort (both procurement and R&D investment) will decline as a driving force in United States technology, and will move toward acquiring its increased fractions of its technology from commercial sources (foreign as well as domestic).

— The national laboratories, which perform twice as much government funded R&D as universities, will find themselves with insufficiently compelling missions to sustain their current levels of effort, but efforts to re-mission or downsize them will be met with strong political opposition.

— The universities will lose some of the autonomy they have enjoyed in research and will become more deeply engaged with creating "useful" knowledge and accelerating its diffusion to the private sector, but will continue to focus primarily on basic research open to all.

— State governments will become increasingly sophisticated in the services they provide to small and medium sized businesses to improve their productivity and

to attract capital investment, and the federal government will expand its encouragement to and cooperation with the states in this endeavor.

— International cooperation will increasingly influence American science, especially in its dependence on major facilities or foreign access, and basic technology development as governments begin to internationalize some of their civilian technology development activities to reduce trade frictions.

— It is increasingly anomalous that government, which is the source of finance for half the nation's R&D, insists on invoking three different and incompatible economic paradigms for technology generation, depending on the whether the purpose of the technology is to meet military, commercial, or environmental markets. Defense technology is generated in a command economy; economic competitiveness is left to a *laissez-faire* policy; and environmental technology is forced by regulatory pressures. The United States is moving toward a more integrated industrial technology base. That industrial base is increasingly integrated into the worldwide economy. That integration suggests that there will be a convergence of the policy tools for guiding technology in all three areas: military, commercial, and environmental.

The basic law that defines United States technology policy is the National Science and Technology Policy, Organization, and Priorities Act of 1976.² The occasion for this statute was the legislative establishment of the Office of Science and Technology Policy in the Executive Office of the President during the administration of President Ford. President Nixon had disestablished the predecessor Office of Science and Technology, which was a White House office and not protected by statute. The 1976 Act for the first time documented the government's role in technology, and is often referenced in subsequent legislation about critical technologies or technological priorities. The Act gives some policy criteria for federal investments in technology for purposes other than established government missions:

"It is further an appropriate federal function to support scientific and technological efforts which are expected to provide results beneficial to the public but which the private sector may be unwilling or unable to support."³

"Explicit criteria, including cost-benefit principles where practicable, should be developed to identify the kinds of applied research and technology programs that are appropriate for federal funding support and to determine the extent of such support."⁴

² 42 U.S. Code 6,683.

³ Section 6,602, (b) (3).

⁴ Section 6,602 (c) (2).

The *de facto* United States technology policy is, indeed, shifting rapidly from its emphasis on development of technologies to serve missions assigned to the federal government, particularly in the defense, space, and nuclear fields, to programs intended to enhance the economic performance of private industry. The general directions of policy evolution were laid out by Dr. D. Allan Bromley in 1990 in the first formal declaration of technology policy by the Bush administration.⁵ The year before, President Bush had publicly declared his intention to provide cost-shared support for "precompetitive, generic" technologies of value to commercial industry, as indeed the Congress had authorized in the 1988 Omnibus Trade and Competitiveness Act.

During 1992, perhaps in response to the upcoming presidential election, the Bush administration substantially accelerated its initiatives in technology support to the economy even as its political rhetoric continued to warn against industrial policy. It requested growth in the Advanced Technology Program in the Department of Commerce to US\$69 million for fiscal year 1993. It announced new R&D initiatives in high performance computing and communications, advanced materials and processing, and in the non-defense component of manufacturing research and development. It continued its investments in the National Research and Education Network.⁶ A substantial acceleration of policy change can be anticipated under President Clinton if the incoming administration implements the strategy described in the September 21, 1992, statement of the Clinton-Gore presidential campaign organization⁷ and a related statement of manufacturing strategy. These policies (together with others addressing national security, environment and health) represent an acceleration of ideas for federal activity in support of industrial competitiveness that differ from initiatives already taken by the Bush administration and the Congress primarily in their pace, scale, and the level of confidence in their effectiveness.⁸ Nevertheless, there is still a weak consensus on the appropriate roles for government funding of science and technology in support of economic performance.

⁵ Bromley, D. Allan. *The U.S. technology policy*. Washington D.C., The Executive Office of the President, Sept. 26, 1990.

⁶ Branscomb, L. M. Technology policy and economic competitiveness. In: *Science and technology policy yearbook 1992*. Washington D.C., American Association for the Advancement of Science, 1992.

⁷ *Technology: the engine of economic growth* (Clinton-Gore campaign document issued Sept. 21, 1992).

⁸ The elements of policy include: (a) support for R&D in support of the commercial industrial base (a civilian Darpa is mentioned, but the program seems similar to ATP in commerce); (b) an aggressive program to build 172 manufacturing extension centers, building on the current NIST MTCs; (c) investment in information infrastructure (an extension of the current NREN program to schools, libraries and hospitals); (d) a focus on human resource development — with one welcome addition to current federal activities: an apprenticeship program on the European model to address school to work transition for the non-college bound.

Indeed, it is unclear how enthusiastic the Clinton administration will be for technology investments as a tool for economic revitalization. Despite many strong statements on the campaign trail, the transition period after the election saw great prominence given to the "economic team" of senior officials in the new administration, but the president's Advisor on Science and Technology — a position ranked with the Director of the National Security Council — was not among them. The nomination of Dr. John Gibbons (the director of the Congressional Office of Technology Assessment) to this post was made with virtually no fanfare or media attention, quite surprising in view of the prominence given to the appointments of others to this office and the central role science and technology are said to have to the economy.

2. Postwar science and technology policies⁹

During the four decades after World War II, the United States attained the highest level of scientific and technological achievement in history. With the world's largest economy and the strongest armed forces, it helped to defend the cause of free society. It did so with outstanding success. New industries with revenues of hundreds of billions of dollars were created from scratch after the war, born from the creative powers of American science and engineering. As by-products of investments for defense, the aviation, computer, and microelectronics industries became leaders throughout the world. American universities attracted the interest and admiration of all countries, and they still attract one third of all the students in the world who study abroad. In only five years, Americans created the organization, the facilities, and the technology for manned exploration of the surface of the moon.

The policies under which these achievements occurred were clearly articulated in Vannevar Bush's report to President Truman, entitled *Science, the endless frontier*.¹⁰ The period from the early fifties to about 1968, when the growth of American science came to a halt for 10 years, is often called the

⁹ For an historical analysis of post war U.S. science policy, see Smith, Bruce. *American science policy since World War II*. Washington D.C., The Brookings Institution, Apr. 1990. For an analysis of U.S. technology policy, with emphasis on national security and economic concerns, see Alic, John; Branscomb, Lewis M.; Brooks, Harvey; Carter, Ashton & Epstein, Gerald. *Beyond spinoff: military and commercial technologies in a changing world*. Boston, Harvard Business School Press, 1992. For an annual summary of issues, documents, and data about U.S. science and technology policy, see Meredith, Margaret O. Nelson, Stephen D. & Teich, Albert H. (eds.). *Science and technology policy yearbook 1991* (and annually). Washington D.C., American Association for the Advancement of Science, 1991 (and annually). Other recommended references will be found in the Annotated bibliography at the end of this paper.

¹⁰ Bush, Vannevar. *Science, the endless frontier*. Washington D.C., National Science Foundation, July 1945, reprinted 1960, 1980, and in 1990. pp. 5-40.

"golden age of American science". It was the best of times for scientists in American history.¹¹

The essence of the post-war policy for science and technology had two parts: (a) governmental support for research in basic science; and (b) active development of advanced technology by federal agencies in pursuit of their statutory missions.¹² Dr. Henry Ergas characterizes this policy, like that of Britain and France, as "mission-oriented" technology policy.¹³ He contrasts this approach with the "diffusion-oriented" policies of Germany, Switzerland, and Sweden, which is an alternative approach to national technological development.

Thus five assumptions have characterized United States S&T policy since World War II:

(a) basic scientific research is a public good. Investment in it, especially in combination with higher education, leads, through a sequential process of innovation to the creation of new technologies which in turn may spawn new industries;

b) in fulfillment of the government's responsibilities for defense, space exploration, and other statutory responsibilities, federal agencies should aggressively pursue the development of new technology for use in these missions. The technological fruits of such a mission-driven, high-tech strategy will automatically and without cost to the government "spinoff" to commercial uses, thus further stimulating industrial innovation;

(c) by refraining from direct investments in research to create technology specifically for commercial exploitation, and leaving to private industry the responsibility for tapping into these two sources of science and technology support, the reliance on market forces to stimulate industrial competitiveness is not compromised;

(d) complementing the centrally-directed, publicly-financed strategy for developing military technologies and the *laissez-faire* strategy for developing commercial technology, a third strategy for environmentally useful technology has relied on the use of regulation to force private investment — a strategy based on the idea that environmental costs have only a negative impact on the economy, which

¹¹ It was not the best of times from a civil liberties point of view, for this is when Senator Joe McCarthy was challenging the patriotism of many scientists.

¹² Smith, Bruce L. R. *American science policy since World War II*. Washington D.C., Brookings Institution, 1990. pp. 48-52, and 164-6.

¹³ Ergas, Henry. Does technology policy matter? In: Guile, Bruce R. & Brooks, Harvey. *Technology and global industry: companies and nations in the world economy*. Washington, D.C., National Academy Press, 1987. p. 192.

fails to reflect a huge future world market in environmentally useful technologies;

(e) United States science and the economy have been sufficiently strong that government viewed science and technology as assets to be deployed internationally in support of political goals and building alliances to contain the Soviet Union. Technologies such as rockets, nuclear fusion and fission, and surveillance from space were deployed in the interests of free world security; the "peaceful uses of atomic energy" program, the civilian exploration of space and the Landsat program were designed to make these military-driven technologies more acceptable to publics at home and abroad.

Each of these elements of American policy after the War II entailed a tacit assumption about the mechanism through which government investments in research and development would contribute to industrial innovation, and hence to the competitiveness of American products in the world market. These two assumptions are derived from a "supply-side" picture of how the process of innovation works industry based on high technology.

Governmental support of basic research is justified, economists say, because the social returns from basic research exceed its cost, but the private returns to a firm investing in basic science are less than its costs because of low appropriability of the benefits. Professor Edwin Mansfield's analysis of all the evidence suggests that the social return from basic science in the United States in the late eighties was about 28 per cent.¹⁴

"Pipeline" and "spinoff": images of the contribution of science to technology

The bipartisan support for science in the United States Congress has rested heavily on the acceptance of the "pipeline" model of the process by which that social return arises in the form of industrial innovations.¹⁵ This conventional, but now discredited, model assumes that innovations arise in the research laboratory or the inventor's shop, and are produced after a sequence of steps through applied research, development, design, and production. It is further assumed that this process is more or less automatic and inevitable, in which case a science pol-

¹⁴ Mansfield, Edwin. Academic research and industrial innovation. *Research Policy*, 20: 1-12, 1991.

¹⁵ Kline, Stephen. Models of innovation and their policy consequences. In: Inose, H.; Kawasaki, M. & Kodama, F. (eds.). *Science and technology policy research: "what should be done? What can be done?"* Tokyo, Mita Press, 1991. pp. 125-40. For background, see Kline, S. & Rosenberg, N. An overview of innovation. In: Landau, Ralph. & Rosenberg, Nathan. (eds.). *Positive sum strategy: harnessing technology for economic growth*. Washington D.C., National Academy Press, 1986. pp. 275-306.

icy oriented to basic research is, in effect, a necessary element of a successful technology policy and assumes a prosperous economy.

The "pipeline" model is not a bad description of how new industries arise from new science — a process that takes a decade or more. The model served the United States well during the post-war period of reconstruction when it had no serious competition from overseas in the field of advanced technology. The emerging biotechnology industry owes its origins primarily to the research in the science of molecular biology, genetics, and biomedical science funded by the National Institutes of Health. In the last decade NIH has invested over US\$60 billion in research conducted in the NIH institutes and in universities funded by NIH. The pipeline model is, however, inapplicable to the way established industries compete through rapid incremental progress.¹⁶ The "pipeline" model is an even less appropriate description of how firms in high-technology compete in the nineties.

The second arm of American post-war policy has expressed faith that the technology created in pursuit of governmental missions will automatically flow to industry and will make for a prosperity. The process through which this is presumed to happen is called "spinoff".¹⁷ A key reason for its appeal is that "spinoff", like the "pipeline" from basic science to innovation, is assumed to be automatic and cost-free. Both of these assumptions, drawn from "supply-side" economic ideas, have the attractive feature that if they are automatic and cost-free the government does not have to "pick winners and losers" in order for the economy to gain the benefits. Government can then claim that its policies achieve the goals of economic growth without interference with the autonomy of private firms.

While "spinoff" has, in fact, never been either automatic or cost-free, there are examples of commercial products "spun-off" from military developments. A classic case is the Raytheon Corporation's microwave oven, the trade name of which, the Radarange, discloses its military origin. Most cases of successful "spinoff" occurred soon after the World War II, when military research and development in the United States dominated commercial research and development. Even as late as 1960, American expenditures for military research and development were a third of all the expenditures for research and development, public and private, by all the member-countries of the Organization for Economic Cooperation and Development put together. Today it is only one seventh, and is predicted to be more like one tenth by the year 2000.

¹⁶ Gomory, Ralph. From the ladder of science to the product development cycle. *Harvard Business Review*, Nov./Dec. 1989. pp. 99-105.

¹⁷ Alic, J.; Branscomb, L. M.; Brooks, H.; Carter, A. & Epstein, G. *Beyond spinoff: military and commercial technologies in a changing world*. Boston, Harvard Business School Press, 1992.

As a further guarantee against central political control over scientific and engineering activities, American policy after the war called for a highly decentralized responsibility for investing in research and development by federal agencies. Under principles advanced by Vannevar Bush but executed following the Steelman Report¹⁸ a few years later, all federal agencies were to develop the technology needed for their assigned tasks and were also to support a proportionate share of the country's basic research as a kind of "mission overhead" reinvestment in the basic knowledge on which their technology depended. Furthermore the autonomy of academic science was to be preserved by competitive selection, by peer review, from unsolicited proposals.

Dominance of defense R&D

World War II, and the Cold War that followed, dominated government S&T strategy in the post-war period and gave it its "supply side" or "mission-oriented" character. In 1960 United States defense R&D comprised a third of all the R&D, public and private, performed in all the OECD countries.¹⁹ United States military R&D was, in effect, the sole engine in the non-communist world for technological development of the emerging "high-tech" industries. Military procurement and government-funded R&D were big factors in the early post-war development of the United States electronics, computer, and aircraft industries.²⁰ If the process of diffusion of military technology to commercial firms was slow, no foreign firms were seriously challenging the United States industrial lead in these markets. American universities were prolific sources of new science from which technologies evolved. In contrast with today's environment of Congressional distrust and confrontation in defense acquisition, defense agencies in the fifties and sixties took technical risks and enjoyed a healthier partnership with their contractors. Much of the stimulation given by defense to technology came through adventurous procurement, not through funding of R&D. A massive national science and technology enterprise was built, with many institutional innovations.

Those institutions and relationships shaped the policies we inherit today. Unfortunately they remain rigid and resistant to change. A system of national

¹⁸ President's Scientific Research Board, *Science and public policy: administration for research*. U.S. Government Printing Office, 1947. v. 1, p. 26, usually referred to as the Steelman Report. These recommendations were ordered to be carried out by President Eisenhower in Executive Order 10521, 17 Mar. 1954.

¹⁹ *Beyond spinoff*, loc. cit.

²⁰ In 1960 government expenditures on R&D dominated private investments (US\$8.7 billion to US\$4.5 billion). In that year 80 per cent of federal R&D investments were from defense. In 1963, if you include atomic energy and space with defense, they comprised 93 per cent of the federally supported R&D effort and more than 2/3 of the entire national effort, public and private. In effect, it was the national effort.

laboratories emerged to support Cold War technology needs. Today these government-funded laboratories enjoy a major share of federal research dollars, (US\$20.8 billion in 1992). However, they face uncertain missions and weak relationships with the private commercial sector (see section 4, National laboratories). Industry finds itself divided into two weakly coupled economies — one of defense firms, the other serving civilian markets. Although most of the large prime contractors are subsidiaries of much larger commercial organizations, the barriers between military and commercial units effectively prevent the sharing of technology between them (figure 1).

Figure 1
Two cultures: civil and military innovation

Attribute	Civil	Military
Design driver	Driven by markets	Driven by "requirements"
Innovation style	Incremental	"Big leaps"
R&D intensity	Moderate	High: 4.9 times civil firms
Product cycle	Measured in years	Measured in decades
Technical priorities	Process technology	Product technology
Business priorities	Low cost, high quality	High performance
Production rates	High rates and volumes	Low rates and volumes
Linkage of R&D with production	Integrated R&D, manufacturing, and service	R&D separately contracted and managed
Technology sharing	Success based on proprietary advantage	Government may require sharing with second source

In short, the United States manufacturing economy has two cultures, one military, the other civilian. Government R&D institutions reflect the military culture rather than the civil one. The resulting government activities are out of touch with the fleet-footed, low cost, high quality manufacturing so vital to manufacturers of commercial products.

The social contract with science

Throughout the post-war period, an implicit social contract between scientists and the government balanced the government's commitment to respect scientific autonomy with an undertaking by the scientific community that scientific

excellence would contribute to national well-being. Society would allow scientists to administer the competition for funds and to exercise an honest stewardship of those funds, so long as excellence in science was sustained. This social contract enjoyed bipartisan support in the United States Congress and was essentially unchallenged for four decades. Despite the Mansfield Amendment, which required the Department of Defense to support academic research only if it was clearly relevant to military matters, and despite the program called Research Applied to National Needs (RANN) of the National Science Foundation, the willingness of the federal government to support basic research was very well maintained.

In short, the American policy after the World War II and its "pipeline" and "spinoff" images, sought to avoid affronting the businessmen's abhorrence of industrial policy and the scientists' abhorrence of centrally planned science, while still retaining the benefits of technological stimulation of the economy. The political attractiveness of this policy helps to explain its persistence, despite the fact that its assumptions are no longer realistic today.

Today both the social contract between scientists and government and its assumptions are seriously challenged. Although the Congress and the administration have, in the main, resisted demands for the reduction of governmental appropriations for scientific research, there are warning signs that the long-prevailing social contract has ceased to be adequate. Some of the difficulties concern the political standing of scientists and their institutions.

The scientific community no longer enjoys the unqualified respect of political leaders that it had some years ago. In January, 1992, the president-elect of the American Association for the Advancement of Science, Professor Leon Lederman, a Nobel laureate in physics, warned that inadequate federal support for basic scientific research seriously threatened American science.²¹ His cry of alarm was regarded by many politicians as a cry of "wolf!". Many of them treated Lederman's warning as both self-serving and politically naive, having regard to the large demand for domestic welfare expenditures and concerns about the insufficient competitiveness of the American economy in the world market.

The prestige of universities is declining as well. Allegations of scientific misconduct in federally supported research, criticisms of the accounting practices of the universities in the calculation of overhead costs on government grants for research, dissatisfaction with solicitations of funds from foreign corporations by academic scientists in return for giving them preferred access to the results of governmentally supported research have fostered a cynical attitude towards the universities in the United States.

²¹ Lederman, Leon M. Science: the end of the frontier? (A report from the president-elect to the Board of Directors of the American Association for the Advancement of Science, Jan. 1991.)

The social contract provided that the allocation of federal research funds would be made on the basis of the scientific merit of proposals as determined by peer review. This is now breaking down. With too many investigators competing for too little money, the United States Congress is becoming increasingly impatient with the concentration of awards in the most distinguished universities. Ignoring the long-standing affirmation that grants would be awarded on the basis of merit, Congressional committees each year divert an ever larger percentage of funds for research and development to favored applicants, through "riders" on legislative proposals, referred to as "earmarking". This is the principle of the "pork-barrel", not the principle of merit, and the total funding for academic facilities and related expenditures has grown at a 30 per cent compounded rate since 1988, reaching an estimated US\$1.3 billion in FY 1993.

The situation was depicted by the president's Assistant for Science and Technology, Dr. Allan Bromley, who said — only partly in jest — in May, 1991, that "It used to be that if you probed someone in the universities about their views of Congress, they would often accuse Congress of being a bunch of crooks. Now if you probe someone in Congress about the universities, Congressmen will frequently claim that the universities are full of crooks".²²

A fourth source of pressure on the social contract between scientists and government arises from growing recognition that "supply-side" reliance on the "pipeline", on "spinoff", and on the decentralized allocation of resources no longer meets the economic and social needs of the United States. This has led to a call in the Congress for a rethinking of United States science and technology policy. Frustrated by the apparent failure of America's world leadership in science to assure the international competitiveness of United States high-technology industry, the Congress is turning its attention from academic science to lists of critical technologies (see section 4, Critical technologies). It presses the administration to support "pre-competitive, generic" technology which will be of direct interest to private industrial firms (see section 4, Criteria for government support).²³ In Washington today one hears much more discussion about technology, much less of scientific research. The "pipeline" and "spinoff" metaphors are fast losing their plausibility, as politicians and the executive branch search for a politically acceptable, economically effective, more "demand-oriented" approach to strengthening the base of American technology.

²² Bromley, D. Allan. Science and technology policy: an agenda for the future. (George Washington University Science and Technology Policy Seminar, May 7, 1991.)

²³ *Gaining new ground: technology priorities for America's future*. Washington D.C., Council on Competitiveness, Mar. 1991. *Report of the National Critical Technologies Panel*. Washington D.C., U. S. Government Printing Office, Mar. 1991. President's Council on Competitiveness. *Achieving competitiveness in national critical technologies: policies in support of technology development in America*. Office of the Vice President, Apr. 1991, 8p.

The stability of the relationship between universities and the federal government is now in question. How it is resolved — what the terms of a new social contract might be — will be one of the major S&T policy issues evolving in the next few years.

Four sources of change

Americans now understand that the world has radically changed. But the paradigms on which the post-war S&T policy consensus rests are still firmly planted in many people's heads, especially in Washington, and the institutions of government that will be needed to implement a new consensus have changed hardly at all. But three major changes in the United States will require not only a rethinking of technology policy, but changes in institutions and new international linkages as well:

(a) recognition that defense priorities will no longer dominate the United States federal government's technology policy. Instead defense must face a drastically shrunk production and weapons acquisition base, will have to increase the fraction of the defense budget devoted to exploratory development and prototyping, even as the defense R&D budget decreases. Because the technologies critical to the new force structure will increasingly fall into areas in which commercial industry is ahead of defense industry, especially the information and communications technologies, defense agencies will have to gain access to commercial technologies. This will require radical change in defense acquisition policies and practices;

(b) recognition that progress in modern, science-based engineering depends increasingly on a publicly-provided infrastructure of basic technical knowledge, tools, materials, and facilities. Between the realms of basic science and proprietary technology there lies a large domain of public good technology, whose value in application is clear but in which firms underinvest because of low appropriability of the benefits. Much of this "infrastructural technology" supports the creation and improvement of design and process technologies. Such capabilities concurrently support military, commercial, and environmental goals. But reliance on "spinoff" from mission-oriented government R&D, on generation by hard pressed private investors, and on technology-forcing through administrative and tort law does not provide the nation with the long term capability to remain both a technological and economic leader. In short, we need a publicly supported technology base, supporting industry's capability to create technologies for all three areas of national need;

(c) recognition that economic performance in a competitive world economy rests primarily on how well the society uses the existing base of technology, skills, and

scientific understanding, and only secondarily, and accumulated over time, on annual additions to this stock of capability. It follows, then, that the government's technology policy must give much greater emphasis to the diffusion of technical knowledge and skills. The primary elements of a diffusion strategy are: aggregating, evaluating, communicating, and absorbing non-proprietary information. The primary mechanisms are through education, mobility of technical personnel, and networks (both facilities and institutions) for promoting cooperation and sharing. The states, as well as federal agencies, have major responsibilities here, especially for industrial extension services.²⁴

End of the Cold War

The revision of defense strategy is driven by a change in requirements and the necessity of meeting them with significantly reduced investment. World events suggest that the risk of either strategic nuclear confrontation or large-scale conventional war with the Soviet Union are rapidly receding. However, the danger of regional conflict with unexpected spillovers has not abated. The outbreak of old ethnic and nationalistic tensions suggests that this risk may even increase. Furthermore the range and destructive potential of weapons increasingly available to Third World countries increases the danger of terrorism and regional conflict. New priorities in defense will be called for:

— Command, control, communications and intelligence (C³I) will continue to be of the highest importance, both for regional conflict and for arms control compliance.

— Mobility of forces, smart weapons for pin-point targets, ability to limit collateral damage, capability to deal with individual and state terrorism, all seem to be priorities.

These capabilities, particularly those concerning C³I and logistics, are strongly rooted in "dual use" technology. All of them require a strong base of science and of generic "building-block" or enabling technologies. As the Defense Department restructures its force structure, a technology strategy should be developed to sustain it. This strategy should include explicit provision for:

(a) a system for establishing military requirements that takes the capabilities of commercial as well as defense industry as the starting point, to achieve the most cost effective compromise between optimal functionality and minimum cost;

²⁴ Shapira, Philip. *Modernizing manufacturing: new policies to build industrial extension services*. Washington D.C., Economic Policy Institute, 1990.

(b) the development of selected prototypes for field testing since fewer new weapon systems will be produced, and higher confidence in their estimated costs and functionality is needed before commitment to production;

(c) expanded fundamental research and exploratory development to broaden the inventory of technical knowledge and increase the spectrum of technical choice, including more emphasis on process technology essential for minimizing production costs and maximizing quality;

(d) changes in the defense acquisition system that will encourage commercial firms to sell to the military without compromising their proprietary interests and will give defense agencies effective access to the best commercial technology.

Such a policy would serve both defense needs and the needs of the industrial sector. It will increase the ability of the civil sector to support future defense needs, particularly in design, production and quality — the primary focus of competitiveness concerns. It is a policy that makes sense whether or not the civil agencies — Commerce, Energy or NSF, for example — are charged with investing in the nation's technological comparative advantage. Putting such a policy into effect faces very serious political obstacles; few are sanguine that it will be successful any time soon.

Rise of economic competition

It should come as no surprise that the images of innovation on which United States technology policy has been based should be reexamined. The United States is in a different world from the one it inherited after World War II. There is no reason to believe that policies that worked so well in the fifties and sixties will work well today. A multipolar world is emerging in which international economic competitiveness and environmental health are replacing military strength as the most urgent objectives of national and worldwide security.

The economic integration of Europe is expected to take a great stride forward in 1993. Its integrated market will be both opportunity and a competitive challenge for American firms. The emerging countries of Eastern Europe are attempting to reorganize their economies to give a central position to the free market. In those countries, virtually every aspect of the way in which industrial innovations occur, technology is diffused, and producers collaborate and compete must be learned and institutions created to support them. The United States economy will be challenged to help them succeed, and to make the investments that may allow Americans to benefit in the future from the economic success of the new States which replace the communist regimes of the USSR and Eastern Europe.

Many of the economies of nations in Asia, Latin America, and Africa are also under stress, and the industrial democracies can no longer ignore their plight. There is growing awareness that the world cannot achieve a stable physical environment, or beneficial international trade, unless the needs of the developing countries are taken into account. New policies through which the developing countries can acquire technologies to support their development in a more environmentally sustainable way will be required.

At the same time there has been a great shift of economic production to rapidly industrializing nations in South America and Asia, where Japan has joined the leaders of the world economy. Forty per cent of the gross national product of the entire earth is now produced in the United States and Japan, with the Japanese share increasing.

Economists argue about whether the economy of the United States is suffering from long-term structural weakness or whether it is only experiencing the transient strain of structural dislocation in a very active world economy. Nevertheless, the pronounced diminution of the American share of world markets in machine tools, semiconductors, telecommunications and office equipment forces us to ask: why has the comparative advantage of the American economy declined so sharply in these science-intensive industries in spite of American achievements in science and technology?

The short answer is that American firms, and the government of the United States, have been much too slow to recognize the power of modern science and engineering to transform the way products are designed and produced. They have also been slow to take advantage of new forms of industrial organization and management through which technology is used to reduce costs, increase quality, and accelerate responses to market forces.

Changes in science, engineering, and innovation

New ideas are now required in many areas of modern industry. The ideas on which we used to draw in thinking about industrial innovation are no longer adequate. Japan has been a particularly fertile source of these new concepts, many of which are expounded by Prof. Fumio Kodama in a book which was awarded the Yashino Sakuzo prize in 1991.²⁵ These new ideas have rendered traditional concepts of product development and mass production out of date; they are now being adopted on a worldwide scale.

The new conceptions of industrial innovation focus on the process of production; they do not take research and development as points of departure. They must be described by a model of innovation which envisages mutual interactions

²⁵ Kodama, Fumio. *Analyzing Japanese high technologies: the techno-paradigm shift*. London, Pinter Press, 1991.

between design, production, marketing and research, not by a sequential "pipeline" of activities starting with research, ending with marketing. These new approaches to innovation have changed the level of performance required for being competitive in world markets. Some examples include the use of computer-integrated manufacturing using "intelligent tools" to break the connection between economies of scale in production and the lot size of similar parts.

Quality is increasingly controlled through the accurate characterization and precise control of industrial processes, rather than by testing after production is completed. Processes and systems of production (rather than research and product development) are becoming primary elements of the strategy for achieving products of low cost and high quality. Incremental improvements in products are being made by manufacturing and process engineers rather than by specialists in design and in research and development. This is a radical departure from the traditional process of sequential development and production.

Various forms of alliances and relationships of industrial firms are being used as alternatives to vertical integration as means of gaining the benefits of technological specialization. Technological diversification is being used by established firms to guard against competition from enterprises experienced in technologies unfamiliar to the particular industry of the established firms.

"Trickle-up technology" is another Japanese innovation. Japanese electronics firms introduced new technologies, such as liquid crystal displays and low-power CMOS integrated circuits, in wrist watches and other consumer products, while most American companies derive new technologies from their most sophisticated business products, such as mainframe computers. The American approach has the advantage that expensive business products can generate high revenues to pay for the development of the technology, and the first implementations of it in products can tolerate high initial costs. With experience, these costs are reduced and the technology will appear in higher volume, lower cost products, such as those consumers buy. The Japanese "trickle up" strategy, on the other hand, gives the firm much earlier experience with high volume manufacturing of the technology. By keeping the initial performance requirements modest, this early manufacturing learning gives these firms a very low cost production capability, which can then be used to enter markets for more expensive business products with a substantial cost advantage. These new approaches to industrial activity and others like them have many consequences.

While most of these new approaches emerged in "high-technology" industries, we now understand that the right criteria of "high-technology" is not complexity of the product or novelty of its function, but is the choice of the pattern of production that makes the most intelligent use of materials, energy, and human resources. Any business can and should make use of the best practices from high technology. Firms using high technology are rapidly shifting from primary dependence on capital and labor resources to dependence on research and development as the primary resource for remaining

competitive. In Japanese high-technology firms in 1991, investments in research and development exceeded the firm's annual investments of capital in production equipment and facilities, a shift made possible by the flexibility of computer-integrated manufacturing systems.

Weakened control by national governments

National governments will have steadily decreasing ability to unilaterally control flows of money, people, technology, and business alliances across national borders. Governments looking for quicker response of their economies to opportunities and challenges in world markets will continue to privatize their own activities, to look to public-private partnerships for achieving public goals, and to international negotiation and collaboration to sustain both economic and political relationships. Furthermore, in consequence of the accelerated mobility of capital, technology, and individuals, and the steady reduction of barriers to trade, national boundaries are rapidly losing their significance as delineating the territories within which innovations are generated and applied. One consequence of these developments is the diminished capacity of any government to control technological movements within and across its own boundaries. It is not feasible to establish and maintain for extended periods a monopoly on any technological innovation.

New policy directions

As the rates of diffusion of innovations accelerate internationally, transnational firms can more easily initiate production in many geographical locations simultaneously. The rates of diffusion of technology within a national economy must become even more rapid if firms of that country are to have a competitive advantage in the international market. The acceleration of technological diffusion must become a major objective of policies for enhancing the economic position of the country internationally. Technology also diffuses much more rapidly as technical knowledge becomes codified. Knowledge gained from learning through experience, on the other hand, is much more difficult to transfer and diffuses through apprenticeship and collaboration at a much slower rate.

Where the increase of economic competitiveness of a firm, an industry, or a country is the object of policy, it is important that the new approaches to innovation foster a drastic reduction in time between the detection of potential market demand and its satisfaction through production in large quantities, thus enhancing satisfaction of consumers and dramatically reducing the cost of product and market innovations. Thus the two main arms of policy debate are:

— Supply-side policy: under what circumstances and through what mechanisms should government make investments in science and technology in support of national objectives, especially economic objectives?

— Demand-side policy: What investments in knowledge infrastructure, in technology access, adaptation, and absorption should governments make, and how can the infrastructure and technical services be made efficient and responsive?

3. United States science and technology: data and trends

United States R&D in relation to GDP; comparative analysis

Table 1
National R&D comparisons — 1988²⁶
US\$ billions — OECD purchasing power parities

Country	R&D spending	Defense R&D	R&D/GDP per cent	Non-defense R&D/GDP
USA	133.7	43.0	2.7	1.9
Japan	47.0	0.4	2.6	2.6
FRG	24.6	1.1	2.8	2.7
France	17.5	3.9	2.3	1.8
UK	17.0	3.3	2.2	1.8
Italy	9.1	0.6	1.2	1.1
Canada	6.4	0.3	1.4	1.3
Netherlands	4.3	0.1	2.3	2.2
Sweden	3.6	0.4	2.9	2.6
Switzerland	3.2	0.1	2.9	2.9
Total non-USA	132.9	10.2	2.3	2.1

²⁶ From table 4.1, p. 89, in *Beyond spinoff*, loc.cit. See footnotes to table in the reference for sources and interpretation.

The United States federal government operates over 750 major research institutions and has under contract a great many more. Some 380,000 scientists and engineers work in 3 thousand R&D centers, laboratories, experiment stations, and related research agencies and bureaus.²⁷ United States expenditures on research and development totaled some US\$130 billion in 1987, larger than the R&D budgets of Japan, Germany, France, England, Italy and Canada in total. Comparing each government's R&D expenditures, the United States government spent, in 1987, 60 per cent more than all those other governments combined.²⁸ Yet more than 30 per cent of United States R&D is devoted to defense related activity, four times higher than that of the other large R&D spenders in the OECD.

The United States spends approximately the same fraction of gross domestic product on R&D as do our main high-tech industrial competitors (Japan and Germany) (see figure 1). In 1990 this was 2.7 per cent for the United States, 2.6 per cent for Japan, and 2.8 per cent for Germany. But the *non*-defense component of this R&D represents only 1.9 per cent of GDP for the United States, and 2.6 and 2.7 per cent of GDP for Japan and Germany.²⁹ The difference is 0.7 per cent of GDP or US\$43 billion — the level of defense R&D spending in 1990.³⁰ Assuming that all three countries are equally efficient in using R&D, one is drawn to one of two hypotheses:

(a) United States defense R&D is at least as effective as civil R&D in stimulating economic performance. If so, it must be possible to find some US\$40 billion in spinoff to private firms from national laboratory research — a conclusion the authors of *Beyond spinoff* cannot support for the economy as a whole;³¹

(b) defense R&D is significantly less effective than civil R&D in promoting economic performance. If so, United States industry competes with a national R&D shortfall of US\$43 billion. This argument motivates many to conclude that the

²⁷ U.S. Bureau of Labor Statistics. *Monthly Labor Review*, Sept. 1987, and Gil, Kay (ed.). *Government research directory*. Detroit, Gale Research, 1985, quoted in Katz, James E. Mechanisms for providing science advice to Congress. (Draft paper for the Carnegie Commission on Science, Technology and Government, unpublished, 9/21/90.)

²⁸ OECD. *Main science and technology indicators, 1990-91*. Paris, Organization for Economic Cooperation and Development, 1990. p. 16, table 2 and p. 20, table 14.

²⁹ Alic, J.; Branscomb, L.; Brooks, H.; Carter, A. & Epstein, G. Op. cit. Table 4.1, p. 89.

³⁰ Ibid. Table 4.1, p. 89.

³¹ See *Beyond spinoff*, chap. 6. Defense R&D is concentrated heavily in aerospace and electronics. In some industries, jet engines and communications satellites, for example, defense R&D and procurement do have a clear stimulating effect on commercial technology. In others, such as computers, the technology flows the other way ("spin-on").

United States must find a way to shift the R&D capacity, and the funds that support it, from current programs in defense and nuclear weapons labs to private industry, or — at minimum — to the government's civilian programs more helpful to industrial competitiveness.

Such a shift, referred to as "defense conversion" is a daunting political task, but it is the argument that motivates much of the Clinton-Gore technology policy.

Sources and performers of United States R&D investment

Table 2 shows the sources of R&D funding in the United States and the R&D performers who spend it. Note that approximately half the United States R&D total of US\$145 billion in 1990 comes from government, and half from private industry. But much of the government's investment is spent in private industry, so industry performs almost three quarters of the R&D in the United States.

Table 2
1990 United States R&D funding: sources and performers³²
US\$ billions

Funding sources	Performer Federal Labs	Institution			Total	Per cent funded
		Univ. run FFRDC's	Industry	Universities		
United States government	16.1	4.8	31.3	11.8	64.0	44.0
Industry			72.9	1.8	74.7	51.4
University				6.8	6.8	4.6
Total (\$B)	16.1	4.8	104.2	20.4	145.5	100
Per cent performed	11.1	3.3	71.6	14.0	100	

The universities perform only 14 per cent of national R&D, and a disproportionate fraction of the basic research. It is also notable that the federal agencies fund only half of the university research; much of the rest is self-funded (although much of that comes from state governments to their state-run universities). The federal and national (FFRDC) laboratories, taken together outperform the universities (US\$20.9 billion to US\$20.4 billion), with more than twice as

³² Table 4.2 from *Beyond spinoff*, loc. cit., p. 92. See footnotes on this table for sources. FFRDCs are Federally Funded Research and Development Centers; the largest of them are national laboratories of the Department of Energy and Nasa.

many federal dollars, a situation now drawing criticism in the post-Cold War period. Within the FFRDC category are some huge technical enterprises devoted to nuclear weapons technology. Three of the Department of Energy's government-owned, contractor operated laboratories, the Los Alamos Scientific Laboratory and the Sandia Laboratory in New Mexico and the Livermore Laboratory in California, have combined R&D budgets exceeding US\$3 billion in total. With the signing of the Start II Treaty, there will be substantial excess capacity in these laboratories — the subject of discussion in section 4, Industrial consortia: anti-trust.

Table 3
Allocation federal R&D spending by subject, 1992³³

Federal R&D budget function	US\$ millions
National defense	43,247
Health Research	9,649
Space research and technology	7,656
General science	2,962
Energy	2,920
Natural resources and environment	1,602
Transportation	1,380
Agriculture	1,091
Education, training, employment, social services	510
International affairs	413
Veterans services	219
Commerce and housing credit	200
Community and regional development	102
Administration of Justice	53
Income security	35
General government	18
Total	72,057

³³ Source: National Science Board. *Science and engineering indicators, 1991*. Washington D.C., U.S. Government Printing Office, 1991 (NSB 91-1). Note that these are functional budget categories, independent of the agency receiving the appropriations. Of course most of the defense function is in defense, health research in the National Institutes of Health and so forth.

Although the budgets of both defense and the Department of Energy National Defense Program (nuclear weapons) are in decline, they are very much larger, even in their shrunken state, than the R&D budgets of the civilian agencies. It is important to remember, as one discusses policy alternatives for new investments in the commercial technology base, or in knowledge infrastructure, that the current budgets for these activities are tiny by comparison to those of traditional defense, space, and energy programs (see table 3). It will take a long time for the Congress to get sufficient confidence in the new technology policy initiatives to bring their funding up to levels at all comparable with more traditional federal missions.

4. Government support for commercial technologies

Critical technologies

Targeted investments by governments in specific technologies that might have been described politically as "critical" to some dimension of the national interest have a long, if sometimes checkered, history. In modern times three categories of technology have received the greatest attention:

- (a) those deemed critical to national security;
- (b) those inherent in nationalized or national-champion industries; and
- (c) others not necessarily called "critical" but receiving high political priority as public goods (for example: air traffic control) or underpinning national projects such as manned exploration of space).

Beyond these categories of specific technologies for national missions and public goods, most governments have indulged in a broad variety of subsidies for technologies of general economic interest. In some cases no specific technology, or even industry, is designated, as in R&D tax credits. In others an industry (computers, aviation, or health industry, for example) is selected for promotion on economic grounds, with the identification of specific technologies left to a process defined by policy and administrative procedures.

In the National Defense Authorization Act for FY 1989³⁴ the Congress mandated the Defense Department to provide Congress annually with a Critical Technologies Plan focusing on the 20 most critical technologies. The first such report

³⁴ Public Law 100-456, section 823.

(listing 22 technologies) was sent to Congress on March 15, 1989.³⁵ The statute defines critical technologies: "the technologies most essential to develop in order to ensure the long-term qualitative superiority of United States weapon systems".

The criteria given in the report for selecting technologies for the list are:³⁶

- Technologies that enhance performance of conventional weapons and provide new military capabilities.
- Technologies that improve availability, dependability and affordability of weapons systems.

The 1990 defense Critical Technologies List contained two additional criteria:

- Pervasiveness in major weapons systems.
- Strengthening the industrial base to "reflect explicitly the growing concern for spin-off to the industrial base".³⁷

As will be seen in the next section, these criteria could apply to the full range of defense R&D investments, and fail to provide much constraint on candidate technologies.

The selection of lists of "critical technologies" as preliminary to formulation of industrial policy first came into vogue in the late eighties in the United States. Of course most nations have indulged in industrial policy, and insofar as they supported commercial technologies on the basis of a set of priorities, those selected might be considered more "critical" to national well-being than others. The Japanese have for some years engaged in net assessments of industrial technologies, a step that surely should be preliminary to the making of critical technology lists, and in collaboration with industry leaders have selected technologies for targeting. The choice of computer technology for the European Community's first "framework" program (Esprit) can be said to reflect the feeling that an indigenous computer industry is essential to European economies.

In the United States the origin of the critical technologies concept has its roots in defense technology policy. This is, perhaps, not surprising in view of the

³⁵ *The Department of Defense Critical Technologies Plan*. Washington D.C., The Department of Defense, 15 March 1989.

³⁶ *Ibid.* p. 5.

³⁷ Moge, Mary Ellen. *Technology policy and critical technologies: a summary of recent reports*. Washington D.C., The National Academy Press, Dec. 1991. (Discussion Paper n° 3. The Manufacturing Forum.)

evolution of United States technology policy from defense-dominated to commercially-oriented. This origin in export control terminology will be significant when we discuss the meaning of the word "critical", which carries an implication that both security and economic interests are involved. This linking of military concerns with the desire to support industrial competitiveness suggests the danger that protectionist policies might become attached to those technologies deemed "critical" and receiving government subsidy.

Critical technologies as a concept for export control

On February 27, 1976, the Defense Science Board published a task force report, commonly referred to as the Bucy Report after the chairman, Fred Bucy of Texas Instruments Co., which recommended a radical reform of export control strategy.³⁸ It proposed that controls should be focused on retarding transfers of technology which could significantly enhance the military capability of potential adversaries. This strategy was seen as particularly useful when applied to turn-key facilities with which both weapons and civilian products could be produced. Thus the new policy would address a troublesome area not adequately dealt with in the Commerce Department's Controlled Commodities List: dual use technology.³⁹ Indeed, one benefit to industry was expected to be reduced reliance on the Controlled Commodities List. Three years would pass before these recommendations were embodied in export control law.

The Export Administration Act of 1979,⁴⁰ as amended in 1985, emphasized the control of critical technologies and assigned this responsibility to the Department of Defense. A key step was the creation by the Secretary of Defense of a "list of militarily critical technologies", which was published in both classified and unclassified form in October 1986.⁴¹ This Militarily Critical Technologies List (MCTL) is not intended to serve as a "control list".

"Rather it provides a detailed and structured technical statement of development, production, and utilization technologies which the Department of Defense

³⁸ Defense Science Board. *Report of the Defense Science Board Task Force on export of U.S. technology*. Washington D.C., Office of the Secretary of Defense, Feb. 27, 1976.

³⁹ Dual use technologies are those applicable to both military and commercial uses. Post-Cold War U.S. military strategy is giving increased emphasis to command, control, communications, intelligence and logistics — all areas in which commercial technologies are strong and defense technology investments are dual use.

⁴⁰ Export Administration Act P.L. 96-72.

⁴¹ The classified MCTL was first published in 1980 and was revised five times by 1986. The first unclassified version was published in 1984. See, for example, the second unclassified version: Office of the Undersecretary of Defense Acquisition. *The militarily critical technologies list*. Washington D.C., Department of Defense, Oct. 1986.

assesses as being crucial to given military capabilities and of significant value to potential adversaries."⁴²

It covers private as well as government-owned technologies. The statute says that primary emphasis shall be given, *inter alia*, to arrays of design and manufacturing know-how, keystone manufacturing, inspection, and test equipment, and goods accompanied by know-how or which might give insight into design and manufacture of a United States military system. Thus the MCTL is not a list of critical military material and weapons systems. It is instead a list of technological capabilities, which in the hands of the industry in a potentially hostile State would give that State the capability to erode an advantage the first State perceives to be essential.

If the industrial capability in question has "dual uses", a factory possessing that capability can, in principle at least, produce civilian goods and/or weapons systems. The Controlled Commodities List did not have this property, for it refers to specific single products. A "militarily critical technology" is likely to include a family of tools and know-how which only in combination create the production capability in question. Increasingly, technologies of military importance are driven by huge commercial markets. In the last decade of the Cold War both nuclear weapons and their delivery systems were approaching both saturation and equality on both sides. Determinants of strategic advantage began to shift to command, control, communications, and intelligence. These functions all derive their primary technologies from the electronics, communications, and computer industries, where commercial technology leads the military by substantial margins. Thus these areas of strategic (and tactical) importance increasingly depend on dual use technologies.

Two consequences flow from this observation:

- (a) the criteria for identifying a "critical" for export control purposes begin to resemble those one might apply in a policy designed to enhance commercial competitiveness;
- (b) for this reason, and even as they cooperated in the Cocom export control regime, some trading partners of the United States became concerned that the MCTL might become an instrument of trade protection under the guise of a tool for protection collective security.

Critical technologies reports

In the United States there have been two major studies leading to lists of "critical technologies" by private industry groups, two from government agen-

⁴² Ibid. p. ii.

cies (Defense and Commerce) and one mandated by Congress to be prepared by the Executive Office of the President.

In 1987, a private trade group, the Aerospace Industries Association, published a study made by many panels of experts from industry, universities, and government laboratories, identifying a number of technologies the industry considered "key" to its success.⁴³ The Association, headed by Donald Fuqua, retired chairman of the House Science, Space and Technology Committee, wanted to induce the government to recognize that the industry it represents has both commercial and military value, and that in promoting economic performance the government should support technology development as well as basic research. Although the technologies it analyzed were called "key" rather than "critical", the study was a prototype for those the Congress would soon ask for.

The computer industry was not to be left behind. The Computer Systems Policy Project (CSPP) is comprised of the CEO and the CTO from each of 11 United States computer firms. Its 1990 report *Perspectives: success factors in critical technologies* identified 16 critical technologies for the future, and discussed the success factors that might guide public technology policy.⁴⁴

Department of Defense Critical Technologies Plan. During the first Reagan administration, the Department of Defense began to express its concern about the state of the civil economy and its future impact on defense should the decline continue. The Defense Science Board, in the study of dependency on foreign sources of supply for semiconductors, which later led to government support for the Sematech consortium, worried about the impact of lagging United States competitiveness on defense interests.⁴⁵ The Undersecretary for Acquisition and Logistics, Robert B. Costello, proposed that the Defense Department invest in the civil industrial technology base because defense production technology was dependent on it. These concerns energized Senator (D-NM) Jeff Bingaman, a member of the Senate Armed Services Committee and the Joint Economic Committee. He and his staff have authored a series of bills that led not only to the requirement for annual reports on defense critical technologies, but the creation of the Critical Technologies Institute to support officials in the Executive Office of the President and leading technology agencies with analysis to support policy making.

The Technology Administration of the Department of Commerce put out their own analysis in 1990, preferring to call its list the "Emerging" technologies

⁴³ Aerospace Industries Association. *Key technologies for the 1990's: an overview*. Washington D.C., The Aerospace Industries Association, 1987.

⁴⁴ Computer Systems Policy Project. *Perspectives: success factors in critical technologies*. Washington D.C., Computer Systems Policy Project, 1990.

⁴⁵ *Defense Science Board Task Force on Defense Semiconductor Dependency*. Washington D.C., Department of Defense, Defense Science Board, Feb. 1987.

report. Their criterion was the potential of the technology to contribute substantially to the economy over a ten year period. The criteria included:

- (a) potential market size;
- (b) contributions to productivity or quality improvement;
- (c) driving next generation R&D and spin-off applications.

The FY 1990 Defense Authorization Act contained an allocation from the Defense budget to finance a Critical Technologies Panel to be established by the Office of Science and Technology that would report biennially to the Congress on technologies critical to meeting national needs (competitiveness, defense, energy security, quality of life). Because any study made by OSTP of critical technologies might heighten pressure on the administration to move toward what it felt was an unacceptable form of "industrial policy", the White House was quite nervous about the Panel's work. When the draft report appeared in the spring of 1991, an article appeared in the *Wall Street Journal* entitled *White House Tries to Distance Itself from Panel Report* and implying that the report was indeed a step down the slippery slope of industrial policy.⁴⁶ The pressure became quite intense; OSTP put out a press release disavowing any such intent, and all identification of OSTP or the Executive Office of the President with the report was deleted. The President's Council on Competitiveness, chaired by Vice-president Dan Quayle, put out a Fact Sheet on April 25, 1991 that acknowledged the Panel report and noted that technology creation was important but stated that, with certain exceptions, administration policy was to leave this task to the private sector.

The second report in this series, prepared by a new panel under the guidance of OSTP, with the help of the new Critical Technologies Institute, was completed in December 1992, and is expected to be published before the end of the Bush administration on January 21, 1993.

The private sector Council on Competitiveness⁴⁷ in March 1991, published a report entitled *Gaining new ground*⁴⁸ which assesses the technologies

⁴⁶ Davis, Bob. White House tries to distance itself from Panel report. *Wall Street Journal*. Apr. 26, 1991.

⁴⁷ Even Americans are confused by the three bodies with "competitiveness" and "council" in their names. The Council on Competitiveness is a non-governmental, not-for-profit group created by John Young, chairman of Hewlett Packard Corp. The President's Competitiveness Council was chaired by Vice-president Quayle and may not survive the transition from Bush to Clinton. The Competitiveness Policy Council, chaired by economist C. Fred Bergsten, is comprised of both government officials and industrial and academic experts, and was created by the Congress in the Omnibus Trade and Competitiveness Act of 1988.

⁴⁸ Loc. cit.

in nine industrial sectors which, together, represent over US\$1 trillion in sales. "The sole criterion for choosing the following technologies is their importance for the competitiveness of the industrial sectors studied."⁴⁹ They identified the strengths and weaknesses of United States firms in the technologies identified, and made comparisons with the capabilities of firms in other nations. Finally the report recommends government actions in light of its findings. This listing of critical technologies has the virtue of less arbitrariness than many of the others. It begins with panels of experts examining each of the nine sectors without prior assumptions about the value of the sector to government or national interest, other than the potential to create wealth and/or employment. Their recommendation is a five year implementation of a national program of investment in "critical generic" technologies. Its other recommendations deal with both diffusion strategy and R&D unlinked to the concept of critical technologies. Thus this report does specify what is to be done with the analysis, rather than leave the issue open.

Creation of the Critical Technologies Institute

As the result of initiatives taken by Senator Bingaman, the Defense Department budget for FY 1991 contained authorization for a Critical Technologies Institute (CTI).⁵⁰ The CTI was to take responsibility for the biennial critical technologies panels established by OSTP, and the funding provided in the first year for the CTI was used to this end. However, the institute was not established until October of 1992 because of reluctance of the administration to see it created and of the Defense Department to see its funds used for this purpose. A lengthy negotiation between the Congress and Richard Darman, director of the Office of Management and Budget, resolved the impasse in the following way: The CTI would be a Federally Funded Research and Development Center (FFRDC) administratively established and serviced by the National Science Foundation, but managed by a council chaired by the director of OSTP, with membership from three other White House senior staff, together with senior officials from S&T agencies listed in the statute, which provide policy direction for the Institute. Funds are transferred from Defense to NSF for the purpose. A competition for the contract attracted many applicants. The award was made to the Rand Corporation of Santa Monica, CA, which operates a substantial office in Washington D.C. Dr. Stephen Drezner, vice-president for Research of Rand, serves as director of CTI.

⁴⁹ Ibid. p. 23.

⁵⁰ National Defense Authorization Act for fiscal year 1991 (42 U.S.C. 6686).

Technologies appearing in the lists

Mary Ellen Mogee has arrayed a table showing each of the above reports and the technologies they included in each of their analyses.⁵¹ The matrix thus formed is remarkably dense; all the reports tend to pick the same technologies. Most frequently listed are:

- Materials: materials processing, composites, optoelectronics, microelectronics.
- Manufacturing: CIM, robotics, artificial intelligence.
- Information technologies: high performance computing, displays, signal processing, human factors, networking.
- Biotechnology: medical applications.
- Aerospace: propulsion, surface transportation systems.

The main differences between the different approaches are: the private sector reports restricted themselves to their own industries. The defense list contains a number of specialized (and surprising to many) weapons systems, such as hypervelocity projectiles and rail guns. The National Critical Technologies Panel list is broadest, including energy and environmental technologies. All these reports focus on the very areas that have attracted the most commercial and government attention already. This tendency may reflect the desire of industry to see government contribute to their core technologies and of government agencies to protect their existing programs and budgets. But it did lead this observer to suggest a contrariant strategy:

"I have a problem (...) with the temptation to restrict activities to the list of critical technologies officially promulgated by OSTP. I do appreciate the need to provide priorities for investment, but I strongly prefer a process for priority making that is flexible enough to identify new and exciting opportunities that might not be on someone's list."⁵²

⁵¹ Mogee, M. E. Op. cit. pp. 16-7.

⁵² Branscomb, L. M. Testimony at hearing on H.R. 5231: the National Competitiveness Act of 1992, before the Subcommittee on Technology and Competitiveness, Committee on Science, Space, and Technology, U.S. House of Representatives, June 3, 1992.

Authors at the Rand Corporation are preparing a study⁵³ for the OSTP Critical Technologies Panel on foreign targeting of technologies. They also observe that countries targeting technologies select essentially the same list that appears in the United States critical technology studies.

Criteria for "critical technologies lists"

The word "critical" carries little meaning to support policy; it clearly implies high value, and implies that important strategic objectives may be unobtainable in its absence. Thus the loss of advantage in a "critical technology" might be thought a serious blow to the plans of its possessor. But criticality is clearly context specific. Insulin is critical to a diabetic, but to no one else. The patent on the use of selenium as a photoconductor was critical to Xerox, until the day the 17 year patent ran out, but selenium would not be a critical material in the Defense Department's inventory of critical materials. A lithography system capable of patterning 0.35 micron circuit elements on a silicon wafer will be a critical technology to a microchip manufacturer, and probably to the nation whose industry enjoys strength as a microelectronics producer, but not to equally strong economies that are content to buy their chips from others.

Thus an economist might try to calculate the economic return from a technology, and identify as critical the civilian technologies of greatest economic importance. A scientist will consider critical those tools without which his science cannot be explored. An historian might consider critical a technology whose introduction had the most profound effect in shaping the mores and institutions of society.

Corporations have diverse approaches to attaching strategic priorities to technologies. We can divide industries into two groups: those most sensitive to monopolies based on legally protected intellectual property, such as pharmaceuticals and software, and those with broad ranges of technical choice. The former group will, quite obviously, consider as "critical" those patents or copyrights that preserve the opportunity to set prices on product value rather than on cost. The latter group of companies will view "criticality" in terms of its business strategy. If the firm characterizes its business as defined by its core technologies, the method of selection of those technologies will define "criticality". The NEC corporation, for example, has a planning methodology which selects from among its available technology futures the smallest number that support access to the broadest range of possible markets. A "market defined" firm in the same industry, however, will select as critical to its future those technologies that, through diversification, best protect its markets from

attack by firms from outside the industry.⁵⁴ The selection each makes may be quite different.

A military organization will consider critical those technologies not yet available to potential adversaries that provide the largest qualitative superiority to its forces, independent of cost. Because such advantages are transient, special importance will be attached to any critical set of tools, materials, or process equipment without which a weapons system providing qualitative advantage cannot be produced. Thus, economic return may be of minor interest. An example would be the United States claim that the sale of highly specialized Toshiba machine tools through a Norwegian intermediary to the Soviet Union enabled the USSR to substantially erode a qualitative advantage in quietness of the United States submarine fleet.

A government, concerned primarily about sustaining the competitiveness of its commercial industry and contemplating initiatives in technology policy, will have yet another set of criteria for defining a "critical technology". These criteria might be based on four sets of criteria: value, opportunities for advantage, opportunities for government influence, and appropriateness for government promotion.

1. Value of a technology. What opportunities for job and wealth creation in domestically located industry are inherent in the technology? What is the breadth of leverage of a technology?
2. The opportunities for differential advantage. Is there enough technical challenge in the technology, or enough opportunity for intellectual property protection, to provide first mover advantage to the successful innovator?
3. The opportunity for a government to influence progress. Would actions by government, such as investing in R&D, targeting procurement, setting standards or providing financial incentives, have the power to influence the rate of commercial progress?
4. The appropriateness of federal action. If the answers to questions 1, 2, and 3 are affirmative, there remains the question whether such government action is appropriate, under economic theory for a competitive market economy and under fairness principles in a democracy. The key issues are likely to be:

— Does the technology, at its current stage of development, exhibit sufficiently low appropriability that private investment will be insufficient to advance it at a satisfactory rate?

⁵³ Unpublished at this writing.

⁵⁴ Branscomb, L. & Kodama, F. *Managing innovation and setting technology strategy in the Japanese electronics and energy industry: some insights for further exploration* (to be published 1993).

— Does the technology have a high enough rate of social return to justify the public investment, either through economic return to the economy or through provision of public goods?

In none of the eight United States studies that have led to lists of critical technologies have such a set of criteria been used in any formal sense. Thus one cannot draw the conclusion that having drawn such a list, it follows that government should invest in the technologies on the list. Nor does existence of such a list suggest what actions government would be justified in taking.

In one sense the adjective “critical” is a qualifier on the government role in direct support of the civil technology base, admittedly an imprecise and ambiguous qualifier. Whatever attributes are associated with the term, they tend to convey a sense of *priority*. A list of critical technologies fails to convey any distinction, however, between the role of government and that of the commercial or education sectors, or the states.

“Critical” does not define *appropriateness* of a government investment in private sector R&D. Appropriateness has two attributes: (a) the fairness of the process of selecting private organization to benefit from public funds; and (b) the avoidance of substituting public for private funds, i.e. investing in public goods. Fairness is a matter of process; restricting government support to public goods rests on economic criteria. These criteria stress low appropriability to the firm in the presence of high social return.

Criteria for government support

“Precompetitive”, “generic”, “strategic”, “enabling”, “pathbreaking”, and “infrastructural” technologies

In the search for simple concepts that capture appropriateness and fairness, the Congress and the administration have used terms such as “precompetitive” (to suggest non-distortion of the market), “generic” (to suggest ubiquitous utility), “enabling” and “infrastructural” (to imply indirect contributions to productivity and to the innovation process).

Generic technology is defined by the Department of Commerce as:

“... a concept, component, or process, or the further investigation of scientific phenomena, that has the potential to be applied to a broad range of products or processes.”⁵⁵ (Thus generic technology is at the applied end of a spectrum of use-

⁵⁵ Title 15 of the Code of Federal Regulations, section 295.2 (b), under 15 U.S.C. 271 et seq. and section 5131 of the Omnibus Trade and Competitiveness Act of 1988 (P.L. 100-418).

ful, but generally non-proprietary knowledge that begins with basic research but extends to tools, methods, materials, and basic processes.)

Precompetitive technology is defined the Department of Commerce as:

“... research and development activities up to the stage where technical uncertainties are sufficiently reduced to permit preliminary assessment of commercial potential and prior to development of application-specific commercial prototypes.”⁵⁶ (There is an implicit assumption that when consortia of competing firms are eager to collaborate in a government project, while fully aware of anti-trust limitations, the project is precompetitive.)

Thus, as noted above, the Advanced Technology Program is restricted to “precompetitive generic” technology. Two other categories of public good technology are recognized.

Pathbreaking technology is defined by the authors of *Beyond spinoff* as:

“High-risk technologies with long delayed (if ever) payoff, but the potential to create new markets and even new industries.”⁵⁷ Because such projects are close to the frontiers of basic science and are often glamorous, they are popular with government agencies. They are also close in spirit to Cold War technology policy traditions, and exploit the linear, or pipe line model of innovation. The best current example of government support for a pathbreaking technology is biotechnology, with much of the stimulation for the new industry coming from biomedical research at the National Institutes of Health. A second example, much less likely to be equally successful, is high temperature superconductivity.

Infrastructural technology is similar in concept to generic technology in its focus on tools and techniques, but also includes technology to support services that comprise the information infrastructure.⁵⁸ As noted in the next section, one of the limitations of the focus on critical technologies is its failure to suggest the importance of technology diffusion. Infrastructural technology is best characterized by the work the Nist (formerly National Bureau of Standards) and the National Advisory Committee for Aeronautics (now part of Nasa) have done for industry over many decades: developing tools, instruments, and test methods,

⁵⁶ Ibid. Section 295.2 (g).

⁵⁷ Alic, John; Branscomb, Lewis M.; Brooks, Harvey; Carter, Ashton & Epstein, Gerald. Op. cit.

⁵⁸ Branscomb, L. M. Information infrastructure: a public policy perspective. In: Kahin, Brian (ed.). *Building information infrastructure: issues in the development of the national research and education network*. New York, McGraw-Hill, Dec. 1991.

characterizing materials and processes, and evaluating and disseminating technical information.

Lastly, there is:

Strategic technology. This label is context dependent. Firms use "strategic technology" to refer to the core competence of the firm. In that sense the notion of criticality comes into play. The National Science Foundation considered altering its taxonomy for R&D by introducing the idea of "strategic research" to cover much of what is more often called "generic" or "infrastructural", leaving "applied research" to refer to problem solving research. The authors of *Beyond spinoff* used "strategic technology" to imply a government industrial strategy. In unusual cases an industry under severe competitive pressure might be considered "critical" to the national security or welfare, justifying a government investment in industry-specific technology. The authors warn that this policy comes closest to displaying the attributes of industrial policy to which most Americans object. The way the Sematech investment was presented to government in the beginning had much of this flavor, for the justification for a government investment (by Darpa) of US\$100 million a year rested largely on a Defense Science Board study of the security threat from foreign dependency in the semiconductor field (see section 4, Industrial consortia: antitrust). A current evaluation of what Sematech is doing might well characterize the investment as "infrastructural", since it is aimed primarily at industry-wide technical standards for incorporating new production tooling into an advanced semiconductor manufacturing line.

The Commerce Advanced Technology Program (ATP).

The Advanced Technology Program, managed by the National Institute for Standards and Technology (Nist) in the United States Department of Commerce, provides cost-shared funding to commercial firms, or consortia of firms, in support of commercially relevant technology. The budget request for this program in FY 1993 is US\$69 million. As currently administered the program does not give priority to any list of "critical technologies", even though Nist provided such a list two years ago. Instead the program is open to unsolicited proposals from firms for work in what the Commerce Department calls "high-risk, high-return research on precompetitive, generic technologies".⁵⁹ In the following section the official definitions of these terms will be discussed. Note that the term "generic" seems to be in conflict with the words "high-risk, high-return".

Proposals found within the constraints of these definitions are subject to a review process that first scores the projects for technical excellence. Those found excellent are reviewed for their business promise and the capabilities

and commitment of the proposing firm(s). Thus the selection process serves up projects that do not *a priori* follow any list of predetermined critical technologies.

The SBIR program

In 1982 the Congress passed a statute at the urging of the small business lobby called the Small Business Innovative Research Grants Program.⁶⁰ The statute requires all federal agencies funding research on contracts or grants to invest no less than 1.25 per cent of this activity in qualifying small businesses. A small business is defined as a firm with less than 500 employees, although most such firms have less than 25 employees. There are no criteria for the kind of work these firms are to be asked to do other than the agency's mission; the assumption is that small businesses can contribute effectively at least to the extent of 1.25 per cent to whatever R&D the agency is conducting. In 1989, the last year for which data are available, some US\$432 million were spent in SBIR, for a cumulative total of US\$1.8 billion. Initially the SBIR program was strenuously resisted by the agencies, which saw it as yet another example of "pork barrel" legislation and a constraint on their autonomy. However, it has proved as politically attractive to the agencies as to the Congress, and objections have faded. The program is designed so that the initial contract or grant is quite small: about US\$50,000. But if the R&D project is successful, a second grant of five times as much can be made to facilitate commercialization of the new technology.

SBIR is one of the few programs in which federal funds are made available to private firms and may be used to support the development of a commercial product. The justification for this market intervention by government is based primarily on the assumption that the development in question was required to fulfill an agency mission. In the case of the Department of Defense, the product might be something the Department wishes to purchase for the military services. But this justification does not apply to the NSF; there the justification is simply political. The NIH is a special case however; its grants can contribute directly to the creation of new biotechnology ventures.

During the presidential campaign Governor Clinton stated his intention to double the size of the SBIR program, raising the minimum percentage to 2.5 per cent. SBIR grants can also work synergistically with Cooperative Research and Development Agreements (Cradas), as small firms receive support for research while collaborating with a national laboratory under a Crada arrangement.

⁵⁹ Technology Administration, U.S. Department of Commerce. *Strategic view*. Washington D.C., Nov. 1991, p. 25.

⁶⁰ Small Business Innovation Development Act of 1982, Public Law 97-219.

Institutional choices

Once policy criteria for investments in civilian R&D are defined, the institutions to perform the R&D must be selected and the mechanisms for selected and funding them chosen. Two sets of institutional choices must be made:

— What civilian agency (new or existing) will be given responsibility for managing the civilian industrial R&D programs?

— What institutions will be relied on for the performance of the civilian R&D — firms, or groups of firms; national laboratories; universities; or combinations of them?

First, let us consider the choice of federal agency.

A new civilian technology agency?

On November 21, 1989, Senator John Glenn, chairman of the Senate Governmental Affairs Committee, introduced the "Trade and Technology Promotion Act of 1989" (Senate 1978). The purpose of this bill was to create in the Department of Commerce an "Advanced Civilian Technology Agency", to support technologies for commercial industry by analogy to the Defense Department's Advanced Research Projects Agency (Darpa).⁶¹ Acta proposed to create a revolving fund to support cost-shared public-private partnerships. This proposal, which was not enacted, is one of many that seek to enlist Darpa in the government's competitiveness strategy or clone it in a civilian agency such as Commerce. A number of proposals have been made to create a "civilian Darpa" or "Carpa". Another proposal, from the Carnegie Commission on Science, Technology and Government, suggested that emphasis be given to the dual use technology mission of Darpa, changing its name to National Advanced Research Projects Agency (Narpa)⁶² in recognition of its dual use activities and new authority to combine efforts with civilian agencies investing in the same technologies. In the FY 1993 defense appropriation, Senator Bingaman found a more acceptable name: reversion to the agency's original name Arpa. A strong case for chartering Arpa with an explicit dual use technology development mission is made by Jeff Bingaman and Bobby R. Inman.⁶³

⁶¹ *Managing critical technologies: what should the federal role be?* Washington D.C., The Conference Board Research Report n° 943, Dec. 14, 1989, p. 4.

⁶² *Technology and economic performance*. New York, Carnegie Commission on Science and Technology, 1991.

⁶³ Bingaman, Jeff & Inman, Bobby R. Broadening horizons for Defense R&D. *Issues in Science and Technology*, 9 (1):80-5, Fall 1992.

This fascination with Darpa as a model for an agency to make investments in the civil industrial technology base has three roots.

— Darpa enjoys an R&D budget of about US\$1.5 billion, 30 times the size of Commerce's Advanced Technology Program.⁶⁴

— Darpa has a small, technically expert staff, with a reputation for low overhead and quick decisions.⁶⁵ (Contracting is largely through acquisition offices in the military services.)

— Darpa's role is investment in technologies of military potential far in advance of established service requirements; it enjoys a high degree of latitude in deciding what these technologies will be.⁶⁶

Of course, there is no reason to believe that calling a new civil agency Acta or Carpa would earn it a US\$1.5 billion budget, or that managers of a civilian agency could ever enjoy the freedom of action of Darpa's managers, who are cloaked in the autonomy that national security uniquely imparts'. Indeed, there are many skeptics about the appropriateness of the concept of a "civil Darpa". One view is to question whether a government agency can do a better job than a sector-specific venture capital or mutual firm at making technology investments in a commercial market.⁶⁷

Another attempt to invent a civilian technology agency free from political interference has been proposed by a report of the National Research Council.⁶⁸ The Research Council's Panel on the Government Role in Civilian Technology recommends that a Civilian Technology Corporation (CTC) be chartered by the Congress and governed by a board appointed by the president and confirmed by the Senate. It would receive a one time appropriation of US\$5 billion in public funds, and would have the authority to make venture capital investments as well as R&D grants and contracts. This "arm's length" relationship to government

⁶⁴ In FY 1992 Darpa's budget of US\$1,586.3 million was comprised as follows: Research, US\$115.8 million; exploratory development, US\$744.4 million; advanced technology development, US\$657.6 million; and management and support, US\$68.5 million.

⁶⁵ FY 1992 personnel: 142 civilians, 25 military, 16 IPAs, total of 183. But 2/3 of Darpa's expenditures are contracted by service and other agencies for Darpa, which minimizes Darpa's administrative burden.

⁶⁶ However, the strongest complaint about Darpa's effectiveness is its success at winning adoption of the technologies it promotes into the weapons systems of the three military services.

⁶⁷ Donohue, George; Bueneke, Jr., Richard H. & Walker, Wayne G. Why not a civil Darpa? *Rand Issue Paper*, 1 (1), Nov. 1992.

⁶⁸ Committee on Science Engineering and Public Policy. *The government role in civilian technology: building a new alliance*. Washington D.C., The National Academy Press, Apr. 1992.

would, advocates say, increase the likelihood that bold and non-political choices of technology investments would be made. Critics point to the suggestion that the board of directors of the CTC, not the president, would appoint the CEO. They recall the reason President Truman vetoed the original bill to create the NSF (then called National Research Foundation). President Truman insisted that if public funds were to be expended, the CEO must be accountable to him, just as the president was accountable to the Congress and the people for the use of their tax monies. He had his way in the present form of the National Science Foundation.

Industrial consortia: antitrust

Interest in encouragement of industrial alliances and consortia has grown rapidly since 1980 under the following influences:

— If government gives R&D subsidies directly to industrial firms, there immediately arises an issue of "fairness". If the benefits flow to a consortium of firms that is open to all who qualify,⁶⁹ instead of to a single selected firm, the government is much less likely to be criticized for interfering unfairly in market competition.

— In the face of strong foreign competition, firms are increasingly looking to industry-wide (horizontal) consortia to sustain essential elements of the infrastructure and the sources of technical knowledge on which they depend.

— United States firms, observing the strength of the Japanese *kieretsu*, are increasingly aware of the power of strong vendor-manufacturer relationships, and are looking to vertical alliances in preference to being vertically integrated.

— Since the advent of the Reagan administration in 1980, antitrust enforcement has been moderated and the Justice Department is increasingly willing to evaluate industry concentration in the world market, rather than the domestic market only.

This trend began with the formation of the Microelectronics and Computer Technology Corporation (MCC), which was not initially seeking a federal sub-

⁶⁹ A politically troublesome issue concerns the treatment of foreign-owned U.S. firms, and specifically the wholly-owned U.S. subsidiaries of foreign multinationals. They are sometimes excluded from government-assisted consortia, but pressures are increasing to base the criterion for participation not on ownership, but on constructive contributions to the U.S. economy (local content, hiring of U.S. nationals in management positions, etc.). See Reich, Robert. Who's Us. *Harvard Business Review*, Jan. 1990.

sidy but did lobby for passage of the Cooperative Research Act of 1984.⁷⁰ For qualifying R&D consortia registering with the Department of Justice, this statute eliminates the threat of treble damages in federal antitrust actions. Today, MCC is focusing much of its attention on enterprise integration through computer networks and other elements of infrastructure for the more than 80 participating firms.

In 1987 a group of 14 semiconductor manufacturers organized the Semiconductor Manufacturing Technology Corporation (Sematech), to improve semiconductor manufacturing. The primary concern of the consortium was the inability of the small and undercapitalized manufacturers of production tooling to keep up with the fast pace of miniaturization of microelectronic circuits, increases in wafer size, and escalating requirements for low defect rates. At the same time this consortium was being organized the Department of Defense, concerned about the rapid loss of market share to Japanese semiconductor producers, made a study of the consequences to the United States military position if it became excessively dependent on foreign sources of supply for semiconductors.⁷¹ Noting that semiconductors are a prime example of a dual use technology, the DSB report recommended DoD support of an effort to ensure the survival of a viable United States industry. In FY 1988 the Department of Defense, through the Defense Advanced Research Agency (Darpa) began matching the private industry investment in Sematech with annual support of US\$100 million. Sematech has enjoyed some success in its efforts; in late 1992 the United States share of the world merchant semiconductor output reversed its downward trend and rose to be marginally higher than the Japanese share. The government investment in Sematech is, perhaps, the closest example in United States experience to a "strategic technology" investment, as described in section 4, Criteria for government support.

The Commerce Department's Advanced Technology Program, described in section 4, ATP, is open to unsolicited proposals from single firms or groups of firms. All of the projects require at least equal cost sharing by the industry. As a practical matter all ATP contracts with single firms are with small to medium sized businesses, and the program clearly prefers multiple company participation especially when one or more large firms are involved.

There are now a growing number of examples of technology-specific projects in which a government agency collaborates with several industrial firms in a project of national interest. After the discovery of high temperature superconductivity, the Office of Science and Technology Policy encouraged several agencies to initiate consortia of firms, universities and national

⁷⁰ Public Law 98-462, 15 U.S.C. 4301-4305.

⁷¹ Department of Defense. *Defense semiconductor dependency: a report of the Defense Science Board*. Washington D.C., DoD, Office of the Under Secretary for Acquisition, Feb. 1987.

national laboratory partners. The Department of Energy supports a technology effort in cooperation with the "big three" United States auto makers and a number of other firms to develop batteries for electric vehicles. A third example is the National Center for Manufacturing Sciences in Michigan, which with 130 members develops and deploys technologies for world-class manufacturing.

From a technology policy perspective, federal support for consortia are a way of encouraging technology diffusion concurrently with technology generation, and is thus a hybrid supply and demand-side approach. However, each of the examples of government participation, ATP excepted, have been *ad hoc* initiatives, usually from the private sector. Each may be a legitimate experiment in technology policy, and more likely to be successful because of the industry commitments to success. But Guston's warning that the distinction between such projects and Congressional "earmarking" of funds for favorite constituents in home districts may become thinner should be heeded.⁷²

National laboratories: future missions

As the incoming administration addresses the way the government's R&D resources are allocated, it will have to review the complex of over 700 federally supported research and development laboratories.

Table 4
Federal obligations for R&D by performer, FY 1992 (est)¹
US\$ millions

	Total	Intramural	Industries	Universities	FFRDC	Other
Total: all agencies	70,427	17,645	31,929	10,475	7,216	3,160

¹ National Science Foundation. *Federal funds for research and development: fiscal years 1990, 1991, and 1992*. Washington D.C., National Science Foundation, 1992, v. XL, NSF 92-322, p. 51.

Of last year's (FY 1992) expenditures of US\$70.4 billion spent on R&D, some US\$24.86 billion — a third of the total — are spent in laboratories funded in their entirety by federal agencies (i.e. the federal intramural laboratories and the captive contract labs, the FFRDCs).

⁷² "Earmarking" — a form of "pork barrel" politics committing federal funds for R&D or research facilities without the project submission to agency processes — was discussed in section 2, Institutional choices.

Diversity is the hallmark of scientific or engineering laboratories. An attempt to classify both public and private laboratories by their environmental influences has been made in an extensive set of surveys of over 1,300 laboratories made in the National Comparative R&D Laboratory Project (NCRDP).⁷³

The largest federally-financed research and development laboratories — not associated with profit-seeking defense contractors — with the most diversified technical capabilities are called "national laboratories".⁷⁴ While the definition is rather imprecise, the "national laboratories" label brings most often to mind laboratories associated with DoE, Nasa, NIH, and Nist and NRL. In this list there are two different forms of institutions:

(a) contractor-operated laboratories like those of the DoE, most of which are government owned (Goco), and other laboratories owned by not-for-profit companies (such as Mitre and Aerospace Corp.).⁷⁵ Among the contractors are industrial firms, universities, and consortia of universities;

(b) government-owned, government operated (Gogo) laboratories like Nist, NRL, Nasa, and NIH, in which the staffs are predominantly or at least substantially comprised of government employees.

This second group exhibits many variations. The Nasa enabling statutes provide some special flexibilities in their personnel policies, relative to the majority of government civil service positions. This is true to a lesser degree at Nist as well. Furthermore, most Nasa centers have a core staff of government employees, whose number has been shrinking, surrounded by a large and growing staff of contractor support people. NIH also enjoys special legislation for their scientific staffs, over and above the unique nature of the Public Health Service on which NIH is based. The Nasa laboratories are also of two types: the space mis-

⁷³ Michael Crow and Barry Bozeman have carried out the NCRDP program since 1984. The taxonomy presented here is from Crow & Bozeman. R&D laboratories in the USA: structure capacity and context. *Science and Public Policy*, 18 (3): 165-79, Jun. 1991.

⁷⁴ It is, perhaps, surprising how difficult it is to create an unambiguous definition that isolates "national laboratories" from other federally funded technological institutions, even though most people will give the same list when asked to name them. For example, many are included in the list of FFRDCs (Federally Funded Research and Development Centers), but many FFRDCs are embedded in other not-for-profit technically staffed institutions, which are not themselves FFRDCs. Furthermore, some national laboratories, such as NIST and NIH, are directly operated by federal agencies and staffed with civil servants; others are contract operations managed by universities or by profit-seeking defense contractors.

⁷⁵ The DoE laboratories are of two types: the weapons labs: Livermore, Los Alamos, Sandia, and the multifunctional research laboratories: Fermilab, SLAC, the Berkeley Radiation Lab, Argonne, Brookhaven, and Oak Ridge.

sion laboratories: Goddard, Huntsville, Marshall, and Cape Canaveral; and the aeronautical laboratories: Langley, Ames and Lewis.

A special kind of federally supported research laboratory is the Federally Funded Research and Development Center (FFRDC). These are not-for-profit contractor-operated research groups serving a single agency's mission in support of that agency's decision making. Some FFRDCs are embedded inside other institutions. There are three serving different clients inside Mitre (FAA, Army, and Airforce),⁷⁶ several inside the Rand corporation. The FFRDCs come closest to carrying out functions akin to that conducted by government officials: aimed at decision support rather than the creation of technologies and artifacts.

Another kind of national laboratory is the scientific facility, where the cost of a leading edge facility is such that sharing among all researchers is necessary. These include optical and radio astronomy observatories, particle accelerators for high energy physics, fusion energy research facilities, oceanographic ships and their support facilities, climate and weather research facilities, and so forth. These kinds of facilities must be continued and kept up to date, and from time to time new ones established, if the United States is to maintain a leadership position in the observational and many of the engineering sciences. While their capital costs are sometimes very large (SSC is an extreme case), their operating costs are usually modest in comparison. In the discussion that follows I will focus attention on the DoE nuclear weapons laboratories. It is the combination of their huge costs and a mission of diminishing scale that creates a policy problem.

Concerns about the federally funded R&D laboratories have a long history, quite a apart from the current sea-change in federal technology policy. The most recent study at the level of the Executive Office of the President was carried out in 1983 by the Federal Review Panel, chaired by David Packard, for the White House Science Council.⁷⁷ Appendix C of their study lists a selection of 39 prior studies. Virtually every review of the federal and national laboratory system concluded that most of the laboratories are substantially (and in some cases purposefully) isolated from commercial industry. Second, industry experts testify to the great difficulty and risk of commercializing new scientific ideas. Even within a single company, such as IBM or GE, moving new technology from corporate research to any of the firm's product development and production divisions requires the full time attention of very experienced managers. Even then success is very chancy.

⁷⁶ At an earlier time all of Mitre would have been considered an Airforce FFRDC. It grew by adding contract work for other military and civil agencies, and some of that work became converted into the FFRDC form.

⁷⁷ Packard, David. *Report of the White House Science Council: Federal Laboratory Review Panel*. Washington D.C., Office of Science and Technology Policy, Executive Office of the President, May 1983.

Suitability of national laboratories for economic mission

To what extent are the financial and human resources devoted to these laboratories appropriate for the new situation? Are their missions, their organizational forms and locations, and their relationship to other technical institutions both public and private appropriate? The incoming administration will address its choices in technology policy with several constraints posed by this spectrum of laboratories, some imposed by circumstances, others by policy choice:

(a) because of the deficit, new and additional R&D resources will be scarce; resource allocation strategies will involve reprogramming and seeking greater leverage from current funding. Federal directly operated and "national" laboratories receive, in the aggregate, about 28 per cent of the federal R&D budget;⁷⁸

(b) federal policy for enhancing economic performance through R&D investment focuses on private industry as the primary source of innovations and the beneficiary of federal civilian technology programs. Technology policy will be an enabling policy, emphasizing public investments to enhance economic performance through knowledge creation, education and training, and technology diffusion to and within the private sector;

(c) given the pressure on defense resources, the strategy will have as a long term goal building a common industrial technology base for both commercial markets and governmental (military and other) missions. The focus for this objective will be dual use technology. National laboratories develop technology applicable in both civil and defense sectors, although the largest laboratories (the DoE weapons labs) serve defense-related missions.

Because of (a) it is important to address the current allocation of federal R&D resources. Of the current annual expenditures of US\$5 billion, some US\$20.8 billion — almost 30 per cent of the total — are spent in laboratories funded in their entirety by federal agencies.

There are strong political pressures to retain the rates of expenditures in the national laboratories, despite their fading missions, by authorizing the laboratories to invest in civilian technologies in collaboration with private firms. The Senate passed a bill in the summer of 1992, The Department of Energy Laboratory Partnership Act of 1992 (S-2566), which would authorize just that. The Bush administration has strongly encouraged the formation of Cooperative Research and Development Agreements (Cradas), authorized in the 1986 Steven-

⁷⁸ About US\$20.8 billion of the total federal R&D expenditure in 1992 of US\$75 billion are devoted to federally funded laboratories.

son-Wydler amendments). The Clinton-Gore technology policy statement proposes that 10 to 20 per cent of DoE laboratory budgets should be devoted to cooperative R&D with commercial firms. Thus, despite the laboratories' relative isolation from commercial innovation, those interested in preserving laboratory budgets and those eager to demonstrate quickly a means for linking federal R&D to commercial firms share a common interest in this policy direction. Opposed to them are those who see the US\$20.8 billion spent in government laboratories as exacting a major opportunity cost inhibiting new initiatives targeted at the civilian industrial technology base.

Alternative policy solutions

Given the size of the labs and the scale of their resources, it is very unlikely that any one policy solution to either re-missioning or downsizing will prove adequate or appropriate. Thus the following alternatives are likely to be used in combination:

Muddle along: make the Stevenson-Wydler Act approach work in context of the labs as they are. While politically the easiest alternative, this approach is not regarded as likely to be sufficiently productive to justify the continued cost of the laboratories.

Triage: shrink the labs dramatically, using a political mechanism akin to the Military Base Closing Commission, and release the excess resources of money and people to the market. While politically unrealistic, this is the course economists would advocate.

Expand work scope: find new federal missions for the labs within the agency legislative mandate. (Energy; automotive; environmental.) Dedicating the laboratories to such expanded efforts leaves unsolved the partnership with industry required to ensure they meet economic and market realities.

Privatize: change the enabling statutes to authorize the labs to perform "R&D for hire" and reduce their federal support as industry funding rises; alternatively try to sell portions of the labs, with their people and facilities, to industry consortia. Britain tried this after the Rothschild White Paper, and many other countries with large laboratories (such as Australia) have tried too. The transaction costs to the firms are simply too high to use such labs profitably.

Legislate a new mission in civilian technology: charter the labs to respond to industry initiatives and to pursue development of industrially relevant technology. If the Congress authorizes the labs to spend public funds on commercial activities, there must be some policy constraints to limit the inevitable perception

that public funds are simply being diverted for private gain. Even if this does not create complaints of unfair, government-sponsored competition, it may invite a level of "earmarking" not yet experienced.

Reassign labs to new agency or to Commerce: change the enabling statutes to shift one, or a few labs, with their budgets intact, to another institutional setting where conditions for effectiveness are better: the obvious candidate is Nist. This idea requires a degree of willingness of Congressional committees to transfer both money and "turf" to one another that is not regarded as likely.

Universities: university-industry research centers

The third institution that can serve to collaborate with federal civil agencies in the creation of technology of economic value is the university, or at least parts of the university (engineering, business, and some natural and social sciences in particular). The universities, beholden to both federal and state governments for financial support, have tended to exaggerate the extent to which they offer the solution to the nation's competitiveness problems.⁷⁹ There are rather severe limits to the extent universities can engage in commercially related activities, and many are testing those limits today.

A study for the Ford Foundation under the direction of Prof. Richard Florida et al. at Carnegie Mellon University has searched out all the university-industry research centers, and found 1,050 of them, spending US\$4.5 billion annually.⁸⁰ This funding comes from federal agencies (34.1 per cent); industry (30.7 per cent); the universities themselves (17.7 per cent); and from state governments and other sources (17.5 per cent). The distribution of support across federal agencies is surprisingly uniform and reflects widespread multiple support. The following percentage of centers receive support from the respective agencies: NSF (54.9 per cent), Defense (45.1 per cent), Energy (33.9 per cent), Nasa (27.3 per cent), and NIH (26.7 per cent).⁸¹ The industry coverage is quite broad too, spanning chemicals, pharmaceuticals, computers, software, electronics, petroleum and coal. Even more impressive is the finding that 57.9 per cent of the centers

⁷⁹ Harvey, Brooks. University-industry cooperation as industrial strategy. In: Lundstedt, S. B. & Moss, T. H. (eds.). *Managing innovation and change*. Dordrecht, Netherlands, Kluwer Academic Publishers, 1989. Chap. 4, pp. 35-46.

⁸⁰ Cohen, Wesley; Florida, Richard & Goe, W. Richard. *University-industry research centers in the United States*. Center for Economic Development, Carnegie Mellon University, Jun. 1992. (A Report to the Ford Foundation.)

⁸¹ These percentages add to 187.9 per cent. The centers were asked from what agencies they receive support. The data show that on average each center is supported by at least two agencies. The figures do not suggest that the agencies are all investing in centers at comparable levels. An agency like NSF may support more than half of the centers, but it may do so with very modest grants.

were founded between 1980 and 1989; the phenomenon seems to be growing quite rapidly. This study strongly suggests that the universities are more deeply engaged in relationships with industry than most people thought. One implication of the study is that some 13.3 per cent of science and engineering doctorates in United States universities may have exposure to industrial culture through participation in one of these university-industry centers.

The greatest value of this level of university involvement with industry is access by the university's science, engineering and management students to industrial culture and problems and the access the participating firms have to students whom they can recruit into their employ. Through the students, universities represent a uniquely effective mechanism for technology diffusion.

How the universities and government will work out their new relationship, with industry as a participating third party is the subject of section 6.

5. Government promotion of technology diffusion

The search for a political and economic middle ground between a *laissez-faire* economic policy and a full-blown industrial policy made little progress until quite recently. A new approach, which appears to have the makings of a consensus, urges the development of a United States "technology policy", in which the federal government helps develop and provide access to the technical knowledge on which the competitiveness of commercial enterprises and the productivity of all United States institutions depend. Among the advocates of an explicit technology policy are science and technology policy scholars, civilian high-tech industry executives (including members of the private Council on Competitiveness), some microeconomists, and influential technology advocates within the Bush administration, including the Assistant to the President for Science and Technology, D. Allan Bromley, and leaders in many technology-intensive agencies and departments.

Allan Bromley, speaking for the administration, made himself the leader of this middle-ground approach by sending to the Congress in September, 1991, a formal document entitled *The United States technology policy*.⁸² Washington wags said that the most important thing about this little-publicized report was its title page.⁸³ But a team headed by James Ling staffed from Bromley's Office of Science and Technology Policy (OSTP) and Richard

⁸² *The United States technology policy*. Washington, D.C., The White House, Sept. 26, 1991.

⁸³ The administration has been very reluctant to embrace the idea of "technology policy" for fear that it would encourage Congressional pressure for federal research and development activities that might distort the market, interfere with private business decisions, and prove wasteful of federal resources — in short activities that border on "industrial policy".

Darman's Office of Management and Budget (OMB) spent 14 months crafting the policy and gaining its acceptance. Building a consensus in the White House for any document with the words "technology policy" in the title was no small achievement.

Beyond establishing the political legitimacy of technology policy, this document advances a technology policy that, at least in its principles, represents an important departure from the 40 years since World War II. This policy has the hallmarks of a "diffusion-oriented" policy.

The five primary goals of United States technology policy, as formulated in this document are:

- (a) a quality work force that is educated, trained, and flexible in adapting to technological and competitive change;
- (b) a financial environment that is conducive to longer-term investment in technology;
- (c) the translation of technology into timely, cost-competitive, high-quality manufactured products;
- (d) an efficient technological infrastructure, especially in the transfer of information; and
- (e) a legal and regulatory environment that provides stability for innovation and does not contain unnecessary barriers to private investments in R&D and domestic production.

The first, third and fourth of these goals focus on increasing productivity through enhanced diffusion, with the latter specifically relating to NREN computer network. The policy statement also calls for collaboration of government, industry, and universities in three diffusion-related areas of opportunity:

- (a) technology transfer and research cooperation, particularly involving small and mid-sized companies;
- (b) building upon state and regional technology initiatives; and
- (c) mutually beneficial international cooperation in science and technology.

Although scholars describe these kinds of policies as "diffusion-oriented," the term "capability-enhancing" is perhaps more descriptive. Such policies are not so much distributive in their objectives as they are aimed at enhanced power to absorb and employ technologies productively.⁸⁴ Capability-enhancing policies are designed to prepare workers for an increasingly sophisticated work environment and develop their problem-solving abilities, to accelerate the commercialization of innovative ideas, to increase the productivity and lower the cost of industrial production, and to increase the capacity of all firms, large and small, to use technology to improve their competitiveness. The net effect of a capability-enhancing policy is to diffuse economic benefits and increase competition not by "picking winners" but by increasing innovative capacity.

Although demand-side technology policy has a long and honored history in agriculture, new tools and techniques brought to farmers by agricultural extension agents, making United States agriculture the most productive in the world, the dominant United States STI policy has been a supply-side policy. Contemporary political accommodation to the idea of a more demand-side "technology policy" began with President Reagan's reorganization of the Commerce Department and acceptance of the 1988 Omnibus Trade and Competitiveness Act (Public Law 100-418). The technology policies established by this act were designed primarily by Senator Ernest Hollings of South Carolina, but they were widely supported by both Republicans and Democrats in the Congress.

The Act gave a new name, the National Institute for Standards and Technology (Nist), and a new mission to the venerable National Bureau of Standards. Nist's new mission includes three programs, all viewed with some suspicion by economic conservatives: the Advanced Technology Program to finance "precompetitive generic" research in commercial firms; an experimental technology-extension program to help smaller manufacturers improve their productivity; and the establishment of manufacturing technology centers in cooperation with the states.⁸⁵ White House skepticism, however, has restricted these three Nist programs to less than three per cent of Darpa's R&D budget, despite a generous congressional authorization. Thus the three Commerce programs must be regarded as very tentative experiments in capability-enhancing technology policy.

⁸⁴ Skeptics of "diffusion-oriented" policy sometimes associate "diffusion" with active policies to transfer information assets from the haves to the have-nots. This is, of course, not how diffusion works, either in molecules or in information. Information diffusion is a random process in which receptors may filter what they need from that which is flowing freely in the public domain. Technology transfer, on the other hand, usually represents a transaction between identified parties, in which information flows unidirectionally between them.

⁸⁵ Technology Administration, U.S. Department of Commerce. *Strategic view*. Washington D.C., Nov. 1991.

Figure 2
Policies for technology diffusion
Access, adaptation, use, and sharing of technology

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- Systematic acquisition, dissemination of foreign technology.
 - Evaluation, adaptation, and dissemination of technical information in the United States.
 - Technical services and industrial extension.
 - Investments in human resources (education, school-to-work, worker training).
 - Collaborative technical activities among firms.
-

Information infrastructure

Public investment in information infrastructure, however, has several advantages over investments in prescriptive megaprojects and technology transfer programs that target specific industries. Infrastructure investment does not predetermine the relative emphasis to be given to any particular sector, whether it be manufacturing, agriculture, resource extraction or services. Information infrastructure allows information flows to follow demand, rather than requiring demand to be predicted. In that sense information infrastructure is enabling.

The Internet, and its proposed successor, the National Research and Education Network (NREN),⁸⁶ are examples of "information infrastructure".⁸⁷ It incorporates both public and private components, emphasizes the diffusion of useful knowledge, and contributes to both vertical and horizontal integration of intellectual and economic activity. Its structure and pricing policies can explicitly provide for equity in access to services by subsidizing academic connectivity. To the extent that it embodies new technology (for example, the gigabit backbone network), NREN anticipates new applications.⁸⁸ By testing such technologies in a research network, NREN will lower the economic risk of their introduction into commercial service.

⁸⁶ Executive Office of the President, Office of Science and Technology Policy. *The Federal High Performance Computing Program*. Sept. 8, 1989. For a convenient summary see U.S. Congress, Office of Technology Assessment. *High performance computing and networking for science*. Washington D.C., U.S. Government Printing Office, Sept. 1989. (Background paper, OTA-BP-CIT-59.)

⁸⁷ The following definition of "information infrastructure" is used in this discussion: "information infrastructure is comprised of those facilities and services whose shared use by individuals and institutions, both public and private, enable more efficient and effective creation, adaptation and diffusion of useful information".

⁸⁸ Mandelbaum, Richard & Mandelbaum, Paulette. The strategic future of the mid-level networks. In: Kahin, Brian (ed.). *Building information infrastructure: issues in the development of the National Research and Education Network*. New York, McGraw-Hill, 1992.

Optimal utility of a new service is determined by the experience of users.⁸⁹ New information services respond to application innovations (such as telecollaboration, distant learning, vertical integration, and consensus management) without requiring government decision-makers to understand the pace of change brought on by information technology. Much of the technology transfer promoted by government policy today specifies the relationships it seeks to promote, forcing information flows into prescribed and sometimes inappropriate channels. It is in this sense that NREN services are considered "enabling".

Cross-subsidization is common in the publicly supported component of infrastructure, reflecting government concern for equity as well as efficiency and efforts to compensate for market imperfections. Elements of infrastructure may be public (such as libraries) or private (such as communications carriers) or mixed (e.g., NSFNET). They may be capital intensive (e.g., NSF supercomputer centers) or labor intensive (e.g., the United States Postal Service). They may be subsidized (as are university research laboratories), private but not-for-profit (such as ANS)⁹⁰ or profit-driven (e.g., Meade Data Central's Lexis/Nexis service). Finding the correct balance of public and private investment and of user charges to ensure the cooperative interplay of such diverse activities is a major challenge for public policy.

Because an essential characteristic of infrastructure is its accessibility, standards also are important issues of public policy. Standards usually evolve through a publicly accountable process. In the case of NREN three sets of standards must be harmonized: the Federal Communications Commission's telecommunications standards for the carriers, the Office of Management and Budget's Federal Information Processing Standards (FIPS) for the government run services, and the American National Standards Institute (Ansi) voluntary standards for commercial components and services.

Information infrastructure depends equally on "hard" and "soft" technologies, both, that is, on the physical network and on the arrangements for locating, adapting, acquiring, and using information supported by software and manual services. Government regulations, or at least policies, must seek to coordinate these hard and soft technologies, so that access and connectivity are enhanced throughout the information infrastructure.

These issues are made more important and more complex by the rapid shift from paper and voice access to government generated information to electronic distribution through digital networks. Electronic information

⁸⁹ The Arpanet was originally conceived as a means for load balancing mainframe computers, taking advantage of the four U.S. time zones. Users quickly discovered the attractions of electronic mail, file transfers among remote collaborators, and other applications.

⁹⁰ ANS is the Advanced Network and Services Co., a not-for-profit joint venture of IBM and MCI Corporations which, working for Merit, Inc., provides the backbone NSFNET service for the Internet.

searching can be both more selective and more comprehensive than with paper; it can certainly enjoy superior economies of scale. Importantly, on-line systems permit user feedback, which, if correctly used by those managing the information collection, organization, and quality, can increase dramatically its value to users. This capacity, however, raises its own issues — how to preserve the privacy of information users while making information services more responsive to their needs.

The government's investment in the National Research and Education Network (NREN), a central part of the strategy to develop the nation's information infrastructure, will make expanded STI services accessible to thousands of laboratories in universities, industry, and government. By aggregating a national market for such services, it can attract investment by private information vendors as well as justify increased government efforts in STI. Agencies should now be planning investments in the data collection, evaluation, user adaptation, and search strategies needed to support the rising demand for information services over the network.

The Internet is widely connected internationally, and provides a vital link between professionals in smaller or less developed countries and the much larger number of scientists and engineers in the larger, wealthier countries. This is a welcome fact in most quarters of government; indeed government agency sponsored networks form the core of the Internet and many of them are international in character.

The fact that the NREN legislation is based on the goal of improved economic performance in the United States means, however, that some politicians may question whether the openness of Internet to foreign participation is consistent with the goal of giving Americans a comparative advantage in international competition. This concern arises primarily in the case of Japan, whose science strength is far weaker than its industrial practice. There is danger, however, that political efforts to put constraints on the unimpeded flow of information on the Internet might be made. Such an attempt I would call "intellectual protectionism." Brazil practiced a reverse form of such protectionism some years ago with its constraints on digit traffic across the border, but these constraints have been substantially removed. This is an area where some international agreements might be merited.

Industrial extension services

The provision of technical advice to small businesses to improve their economic performance is of course familiar in the field of agriculture. From the time of the Morrill Act of 1862, establishing the land-grant colleges for "agricultural sciences and the mechanical arts" the federal and state governments have collaborated to provide technical extension services to farmers. These services also provided for the subsidized diffusion of research knowledge coming from both

federal and state agricultural research stations. This process has been extraordinarily successful; only two per cent of the population is required to feed the other 98 per cent, plus a significant part of the rest of the world.

The analogous service to small manufacturers and other businesses has had much less acceptance and less success, in part because farms produce commodities with little product differentiation within a crop, and the industry is very highly fragmented. When the State helps one farmer reduce his costs and increase his earnings, there is little discernable economic effect on the price his neighbor receives or the demand for his product. Furthermore, the information farmers require has been of a largely generic nature, applicable to a great many of them. Industrial extension services must be much more specifically adapted to the applications of each firm.

In the late sixties the Congress passed the State Technical Services Act, to provide industrial extension services; after a modest beginning, federal funding ceased and little remains of this effort. In the eighties the states began to take initiatives on their own. By 1988, 44 of the 50 states were investing annually some US\$550 million in efforts to promote innovation. Only about 10 per cent of this goes to industrial extension, however.⁹¹ A 1990 National Governor's Association survey estimates that only 11,800 of the 355,000 United States small and medium sized manufacturers (which produce half of United States manufacturing value added) were helped in any demonstrable way by extension services.⁹²

The Omnibus Trade and Competitiveness Act of 1988 assigned to the National Institute for Standards and Technology (Nist — formerly called the National Bureau of Standards) responsibility for establishing in collaboration with states or groups of states a series of manufacturing technology centers, seven of which are in operation or in the process of establishment. The Act also authorized establishment of an industrial extension program with the states, although the Bush administration did not request more than token funding for this activity. The purpose of the manufacturing technology centers (MTCs) is to bring modern production technology to small and medium sized manufacturers. In effect Nist has combined the functions of the two programs, linking the MTCs to state based extension services. An important focus is on the use of programmable machine tools and automation. But increasingly the centers services are being broadened to cover technical management issues such as total quality management and the European quality process standard ISO 9000.

The Clinton-Gore technology policy document notes that in Germany the Fraunhofer Gesellschaft operates some 40 contract R&D centers and uses industry cooperatives to diffuse the technology across industry. In Japan there are 170

⁹¹ Jones, Megan. Helping states help themselves. *Issues in Science and Technology*, 6 (1), Fall 1989. See also Shapira, Philip. *Modernizing manufacturing: new policies to build industrial extension services*. Washington D.C., Economic Policy Institute, 1990.

⁹² Lyons, John. (Director of Nist, private communication.)

Kohsetsushi technology support centers for small business, funded at US\$500 million per year. The Clinton campaign proposed creating 130 United States centers to engage in extension services. The details of this plan are not yet clear. It seems likely that what will emerge is a set of perhaps 30 manufacturing technology centers placed in strategic locations around the United States, each specializing in production tools and processes common to the region. These MTCs would be linked by computer network to perhaps 100 manufacturing outreach centers (MOCs) — much smaller offices with a few extension agents providing "retail" services to small business in their locale. It seems clear that the advice and help they can provide must be in the basic business services area as well as in technology and production.

Whether such an ambitious program will be created is problematic for at least three reasons:

- (a) it depends on matching funds from the states, most of which have considerable difficulty sustaining discretionary expenditures of this kind through good times and bad;
- (b) there are questions about the extent to which such services should be fully self-sustaining financially, since the firms assisted should be able to appropriate all the benefits. In most states only the first visit is free; in some there are recapture clauses in the agreement;
- (c) there are questions about competition between public services and those from profit seeking consultants, although most state programs operate at the entry level of services, where fees are too low to be of interest to professional consulting firms.

If such a national program of extension services is to be created, it will require a high level of cooperation among the states, since all will be sharing the specialized resources accessible through the network. If that obstacle is overcome it may have another benefit. Today the state governments compete with one another to attract job-creating investments, either from direct foreign investment or from United States firms considering relocation. This competition often takes the form of subsidies, either through donated land, tax abatement, or other benefits. The result is that astute firms force state governments to bid against each other, resulting in tax subsidies to firms without any evident benefit to the American nation as a whole. If the states could agree to collaborate in a positive-sum economic game, all would be better off.

6. The universities: a new social contract?

Section 2 described the social contract that expresses the surprisingly stable United States science policy since World War II, and the stresses it is now

encountering. Congressman George Brown, chairman of the House Committee on Science, Space, and Technology knows more about science policy and the functioning of the American technical enterprise than anyone else in Congress. He is a strong supporter of science and has earned the right to point out the vulnerabilities to which the old policy paradigms are now subject. His September 8, 1992 *Los Angeles Times* editorial sets the text. His position is clearly stated: unless the academic scientific community abandons its tenacious claim to autonomy in resource allocation and performer selection as a matter of entitlement rather than a means to serve American interests, even the best friends of fundamental research will feel they cannot, in good conscience, increase academic science budgets when they compete with urgent social priorities.

The same theme runs through the Task Force report issued on September 15 by Congressman Boucher's subcommittee outlining a project for the committee to challenge the effectiveness with which OSTP allocates research resources to agency activities and ensures that the resulting knowledge and technology flow in a timely manner to public benefit.

In September 1992, Dr. James Duderstadt, chairman of the National Science Board, and Dr. Walter Massey, director of the National Science Foundation, chartered a Commission on the Future of the National Science Foundation. Its report to the National Science Board was submitted in early December 1992. The fear that the social contract is already being renegotiated — unilaterally — made many academics and professional societies feel threatened by the very existence of the Commission.

The Commission's recommendations, however, struck a middle ground. It made four points:

— The NSB should not remain passive while enormous changes are taking place in the United States science and technology enterprise, its policies, institutions, and goals. Many of the mechanisms through which science creates public benefits are beyond NSF's control. Many are managed by federal agencies other than NSF. NSF has two choices: take on the entire technological food chain from research to market, or take an active, indeed leading, role in helping the President and his Assistant for S&T formulate a technology policy within which NSF's proper role is defined and linked to the rest of the S&T and innovation enterprise. The first course leads to disaster, the second fulfills NSF's legislative mandate.

— The NSF should continue to support research in the sciences and in engineering, and provide the facilities and infrastructure required for a strong national research capability. The present portfolio of disciplines and activities is broad enough; NSF does not need to expand that portfolio. The problem lies more in maldistribution of funds in relation to technical needs, not the need to add still more kinds of functions to NSF. Nor should NSF allow its engineering centers or its investments in NREN

to be divested to some civilian technology agency (as proposed in one transition document). NSF's grants should continue to insist on intellectual excellence in all it does, foster unsolicited proposals, cherish its "bottoms up" style of project choice, and cling to merit based competitive performer selection.

— NSF must recognize that the United States technical community is weaker than it should be in many fields that are quite exciting intellectually but also could make a very big contribution to the nation's technological comparative advantage. An example is synthetic polymer chemistry. NSF must not allow pressure from disciplinary constituencies to prevent a distribution of resources into its programs and activities that better matches the technical challenges facing America. Instead it should reach out to technically sophisticated people who understand the fields in which American science and engineering are underinvesting, and ask them to participate in an improved resource allocation process that is better matched to national needs than today's programs reflect. This is a job for NSF itself. It should pay more attention to disciplines and interdisciplinary research known to be poorly represented in our universities as we shift our attention from Cold War to a cold economy. More advice from the most technically qualified people with industry experience should be sought. NSF should not tell university scientists what to do; it needs only put properly allocated resources in the paths of bright people.

— NSF must take more seriously the effectiveness of linkages that connect academic science and engineering to the users of the knowledge created, and strengthen those linkages where possible, even as we recognize that those linkages are quite extensive already (see section 4, National laboratories: future missions). The object is not to force university scientists to "get in bed" with industry (NSB should do that) but to ensure that academic researchers have multiple opportunities to benefit from and collaborate with colleagues in industry and others putting science to use. Among appropriate linkage mechanisms, in addition to students going to work in industry, are university centers with industry participation, faculty-industry exchanges, development of the NREN and facilities shared with industry users, support for data evaluation, reviews, and S&T information services, workshops, conferences, and travel.

The academic science community is in danger of being isolated politically on this issue, since there are very large segments of the science community — mostly in federal and national laboratories and some in industry — that have already made their peace with working in a more utilitarian environment where need-driven priorities drive resource allocations even for basic research and where linkages to the processes of research utilization are accepted as an integral part of the research plan. Note that US\$20.8 billion are spent on R&D in the federal laboratory system (including FFRDCs) while only US\$20.4 billion are spent on R&D in universities

(see section 4, Industrial consortia: antitrust). If the new social contract is tied to greater assurance that public benefits will flow from science and the mechanisms for flow are made explicit, it still isn't clear

— How the "negotiation" takes place, or

— What a new "social contract" would look like.

On the first point, the scientific community has little bargaining power; it is going to have to accept what gets served up. Its influence is limited to blaming the politicians for being the instruments of destruction of a public asset. This is likely to get press but produce little in the way of good outcomes. The real negotiation is within the political process dealing with alternative strategies for defining the role of government-funded science — indeed the role of any government activity — in achieving the socio-political agenda being defined now in the election campaign: jobs, environment, security, infrastructure, and fiscal stability. The new negotiation is taking place between conflicting constituencies on these issues. Scientists are on the sidelines. If that is the correct view of the "renegotiation" process, then the right preposition is "social contract for science" not "with science".

On the second point, the political structure of federal policy toward science is, and will be, heavily influenced by factors that have essentially nothing to do with the philosophical elements of relations between government and science. For example, the earmarking of more than US\$700 million of the FY 1992 budget for academic facilities and research has nothing much to do with alternative views of how science diffuses in the economy; it is a power play serving local political interests. Earmarking is a symptom of the fracturing of the current social contract, since it is clear that commitment to autonomy for science is insufficient to prevent the earmarking. The same thing can be said for the other pieces of evidence for the crumbling of the social contract: public alarm over accusations of scientific misconduct, over mishandling of research overhead accounting, over university insensitivity to the loss of American technical advantage through foreign guest scientists and engineers in our best universities.

Underneath all of this evidence that all is not well in the view of academic science held by the public, the media and the politicians, are three other factors which are putting pressure on resources for academic science:

— The recognized fact that having the most Nobel laureates has not protected us from a loss of competitive advantage in important areas of industrial technology.⁹³

⁹³ No one in a position of responsibility ever said it would. But too many spokespersons for science have deliberately fostered the impression that strong science, along with strong defense and space technology would indeed assure a strong economy. These chickens have now come home to roost.

— The pressure on academic science budgets coming from the fading of support from Defense and the deficit-driven budget squeeze. As government policy shifts from a mission-oriented strategy (that relies on spinoff from defense and space and trickle-down from basic science), the universities are likely to suffer, along with industry.

— A growing appreciation, around the world, that under the right incentive structure (with market incentives first but not alone on the list) the private sector does a better job of execution of tasks for society than do big bureaucracies. This push for privatization also tends to cast doubts on the efficacy of federal research investments.

How might a new "social contract" come about, providing another several decades of stable support for academic science and engineering? When one tries to think about what a new social contract might look like, it is not difficult to describe possible new policies. Some of these policies are already identifiable in the Bush administration national technology policy of September 26, 1990 and in Clinton-Gore issue statements. But it is less clear how these policies emerge as elements of a bargain based on a negotiation with each "side" conceding some authority to the other in exchange for some benefit that retains some authority.⁹⁴ Until this issue of finding a new and stable basis for supporting NSF's mission in academic science is successfully addressed, many conflicting expectations will continue to plague NSF, plague the political community, and plague the scientific community.

Universities are being torn by unreasonable expectations of their role in economic performance; to a degree they have themselves to blame. They are also being torn between their commitment to global communities and their obligations as nationally chartered institutions, dependent on national sources of support. This is a special form of the economic policy issue every government must face: what criteria determine whether foreign owned domestic firms are eligible to participate in government funded incentives for improved economic performance. This is what Robert Reich has called the *Who's us?* question.⁹⁵

⁹⁴ The process leading to the social contract in the Vannevar Bush era is more evident in hindsight. There were two clear protagonists in the 1944-48 period. The protagonists were Senator Harley Kilgore (D-Tenn), Vannevar Bush, a Republican yankee industrialist heading OSRD in the Roosevelt and Truman administrations, Harry Truman and his staff (leading to his veto and creation of the National Science Foundation). During this time the National Academy of Sciences was an active (and conservative) influence in the negotiation. In the current discussion the NAS is still a conservative voice, but the technical community is far more diverse than before and speaks with many voices, including the voice of academic engineering, largely unheard 40 years ago.

⁹⁵ Reich Robert. Op. cit., p. 53.

What charges arising from the growing importance of technological capability in international economic competition are being laid at the feet of university administrations?

— By hosting foreign researchers, especially those from foreign firms, and even by accepting endowments for professorships from foreign firms, universities are “giving away” knowledge assets paid for by American taxpayers without fair recompense.⁹⁶

— By hosting one third of all the foreign students in the world, United States universities are engaged in a massive knowledge drain (despite the known fact that most of the best 60 per cent of those students stay in the United States after graduation).

— By publishing everything they learn in open literature, they are favoring foreign firms that are able to commercialize new ideas more quickly than American firms. The inference is that the United States government should invest less in fundamental research; the alternative of course is for United States firms to accelerate their ability to acquire, adapt and exploit new knowledge from all sources.

— By insisting on scientific autonomy — researching those problems interesting to disciplinary academics rather than problems of greater interest to United States industry — universities are diverting scarce government resources to disciplines of low economic value.

— By working primarily within established disciplines and by strong preference for individual faculty investigator support, academics are preventing interdisciplinary research by teams of investigators that would make more rapid progress toward technologies of economic value. And finally,

— By cavalier management of indirect cost accounting and occasional lapses into scientific misconduct, universities are abrogating — or at least endangering — the social contract under which scientific autonomy was assured for the last 40 years.

My conclusion is that universities will have to walk a very delicate line between expecting recognition for the very real contribution they make to the

⁹⁶ This concern was raised in Congressional hearings by the late Congressman Weiss of New York. More recently, legislation was introduced (and subsequently blocked) to forbid unclassified basic research funded by NSF and NIH from reaching foreign firms — an idea that is at one and the same time impractical and frightening.

technological roots of economic performance in this country, and the commitment to truth and scholarship without regard to national boundaries that is prerequisite to their intellectual integrity. Striking that balance successfully is much more important, I suggest, than wiring all the buildings with optical fibers and putting a computer on every desk. The ultimate solution requires that our society discover that its self interest lies in a global market of ideas as well as of goods, and the universities represent our eyes and ears, learning from as well as teaching others.

7. Changing S&T roles for the Defense Department

As noted in section 2, End of the Col War, the sweeping changes in the United States national security situation are causing upheavals of substantial magnitude in the Department of Defense and the nuclear program in the Department of Energy. But Defense was having substantial difficulty selecting, procuring, and managing the technology on which it depends even before the breakup of the Soviet Union and its alliances.⁹⁷ The challenge of strengthening the defense industrial base at a time of rapidly declining resources is very great, and clearly requires a fundamental restructuring of the defense acquisition system.

Dual use technologies

As noted in section 2, Dominance of defense R&D, defense technology is increasingly dependent on sources of technology in highly competitive, global, high-tech industry. The potential for synergy between defense and commercial applications of technical knowledge centers on the concept of “dual use” technology. “Dual use technology” does not mean a technology that has two uses. It means a technology that has an indeterminate number of potential uses, at least some of which are of significant military importance and some are of material non-military importance.

Thus technologies for designing, making and using jet engines, optical fiber cable, magnetrons, boron fiber composites, rocket propellants, infrared sensors, ion implanters, computers, 3-D hydrodynamic codes, and automated turret lathes are all “dual use technologies”. They could, as easily, and perhaps with more accuracy be called “multiple use” technologies.

Some dual use technology is so general in its application that it can support virtually all of the technically sophisticated applications of specialized military equipments and high-function commercial needs. Perhaps the best example is jet engine lubricants, where military and commercial standards are essentially iden-

⁹⁷ Carnegie Commission. *New thinking and American defense technology*. New York, Carnegie Commission on Science Technology and Government, Aug. 1990.

tical worldwide. Another example is optical fibre communications cable or high speed bipolar circuits (although some military adaptation is needed to reduce sensitivity of these circuits to nuclear and E-M radiation).

The "ultimate" example of dual use technical knowledge comes from basic scientific research. Both defense and commercial technologies grow from the same seeds of scientific knowledge, benefit from similar tools, techniques, processes and materials, draw on the same system of education for scientists, engineers and mathematicians.

Defense-commercial relationships

It is noteworthy that the administration and Congress are no longer looking to the Defense Department to provide policy cover for experiments in direct civilian technology support.⁹⁸ Defense has at its hands full downsizing its program and adjusting to new and lower budget levels. Thus the era when Defense was used as a cover for a "surrogate industrial policy" may be drawing to a close. But the new role for defense R&D and its relationship to the commercial sector remains undefined. *Beyond spinoff* calls for a radical change in Defense acquisition policy which requires building bridges between defense agencies such as Darpa and commercial firms.⁹⁹ The purpose of these bridges is not to accelerate the flow of military technology to the commercial sector, but to give the Defense Department access to the nation's best technology, which increasingly resides in the commercial divisions of American manufacturers.

A task force of the Carnegie Commission on Science, Technology, and Government chaired by Admiral Bobby Inman, called for changes in Darpa which would confirm Darpa's practice of investing in dual use technologies and go further by encouraging Darpa to collaborate with civilian agencies concerned with the same technologies and undertake cooperative agreements with commercial firms for dual use technology development. These new relationships would be recognized by renaming the agency National Advanced Research Projects Agency, or Narpa. Senator Jeff Bingaman has introduced a bill implementing this recommendation: The National Advanced Research Projects Agency Act of 1992. As I said in my testimony to the Joint Economic Committee last September,

"Darpa and the rest of the Defense Department is going to have to realize that the United States now lives in a world of technology, most of which is private, a

⁹⁸ Dr. Radford Byerly, Staff director for the House Science, Space, and Technology Committee, noted during the Colloquium that since the Congress failed to repeal the prohibition against transferring budget allocation from defense to domestic civil programs this year, Congress might be tempted to relocate civil programs within defense programs. The motive, however, would not be to draw the mantle of national security over projects some might claim were "industrial policy".

⁹⁹ Alic, John; Branscomb, Lewis; Brooks, Harvey; Carter, Ashton & Epstein, Gerald. Op. cit.

large part of which is not even located in the United States. Defense is going to have to use it."¹⁰⁰

The Clinton-Gore technology policy paper contains a commitment to "review and eliminate barriers to the integration of our defense and civilian industrial base".

8. International issues in S&T

Technology and trade relations

Every one of the four changes described in section 1 entails increased international dependencies for the United States. The breakup of the superpower stalemate creates a multipolar world where international relations are less constrained and offer increased opportunities and challenges. Security affairs will have increased political content and will be more regional in character. Competition in the world economy, with the rise of Asia and Europe as major economic powers, means that the United States will more frequently require the financial as well as political collaboration of other powers, as proved necessary in the Gulf War. International affairs in science and technology can be expected to become more multidimensional, less polarized by the Cold War and more responsive to regional situations and relationships.

If the 1992 United States election campaign is a predictor of President Clinton's priorities, his focus will be on the domestic economy. Despite this, President Clinton world view is fundamentally internationalist. As befits the post-Cold War era he will understand that relations with trading partners such as Mexico and Brazil desire a high priority. The effectiveness of this focus on international affairs will be limited, unfortunately, not only by his domestic priorities, but by the weakened S&T capabilities of the Department of State.

A recent comprehensive study of science and technology in United States international affairs finds the United States government poorly placed to deal effectively with S&T issues in their foreign policy context.¹⁰¹ The commission found "a crazy-quilt of poorly defined responsibilities, inconsistent strategies, and inadequate resources, frequently knotted up and occasionally knitted together by *ad hoc* mechanisms of coordination".¹⁰² The corps of science counselors in United States embassies around the world is outnumbered 3:1 by the

¹⁰⁰ Branscomb, Lewis M. Testimony to the Joint Economic Committee of the Congress, Sept. 12, 1991. Also quoted by Senator Bingaman in his statement in Congress on Apr. 2, 1992.

¹⁰¹ Carnegie Commission. *Science and technology in U.S. international affairs*. New York, Carnegie Commission on Science, Technology and Government, Jan. 1992. pp. 45-6.

¹⁰² Ibid. p. 11.

S&T officers of foreign embassies and consulates in the United States alone.¹⁰³ Government agencies and United States firms alike too often fail to search out and utilize technology from around the world. This will change, but the change may come slowly.

A second trend is a consequence of the increased codification of science and engineering, described in section 2, Changes in science, engineering, and innovation. The codified (theory based) parts of science and engineering, a rapidly growing fraction of technical knowledge, moves around the world with the speed of electrical signals. Together with the strengthening of technical and business relationships among manufacturers who supply each other, firms are distributing their operations geographically. The Asian NICs have taken strong advantage of this trend. It may be of increasing importance to Brazil as well, especially if its economy can be stabilized. This is leading governments to move beyond science as the basis for bilateral cooperation to embrace cooperative projects in technology as well.

The economies of the newly industrialized and, indeed, of many still developing countries have been growing more rapidly than the economies of the highly industrialized democracies, and accordingly offer the major market growth opportunities for the United States. This should lead to an enhancement of S&T relations, which have for so many years been hostage to the Cold War. Competition for these markets is helping stimulate a number of international projects in science and engineering in the fields of basic science, of environment, and of industrial development. An example of the latter is the Intelligent Manufacturing Systems project, the idea of Prof. Yoshikawa of Tokyo University and put forward internationally by MIT. It is aimed at developing new manufacturing systems technologies that offer increased productivity, flexibility, and product quality. The manufacturing technology initiative started by the Bush administration, which will almost certainly continue, and the industrial extension services the Clinton administration is pledged to expand provide a platform for technology cooperation with Brazil and other nations.

United States exports have been growing faster than the domestic economy for some years. Concerns about labor displacement by imports have been high on the political agenda of the Democratic Party. United States trade policy, however, has so far resisted the temptations of more extreme forms of protectionism. The North American Free Trade Agreement seems reasonably assured of enactment. The Nafta may have some short term negative impacts on Brazil, if Mexico moves into agricultural and other products for which Brazil enjoys export trade to the United States.

Aside from the Nafta, however, United States attention is fixed on Japan — because of the huge United States-Japan trade deficit — and the European Community, because of signs that community integration may come at the cost of

¹⁰³ Ibid.

external non-tariff barriers. President Clinton's acceptance of the Nafta and his early meeting with the president of Mexico, even before he took office, does suggest the possibility of extending more open trade throughout Latin and South America. In any case the economic liberalization already achieved in Brazil should be met with more forthcoming trade policies in the United States.

Science and the bilateral S&T agreement

The United States-Brazil bilateral science and technology agreement has been in effect since 1971. It was renegotiated last year, but is being held up pending resolution of differences over handling of intellectual property, to be resolved in an exchange of letters. The United States side is optimistic about a solution, but passage of intellectual property legislation in the Brazilian Congress has encountered an enormous number of amendments and at this writing is unresolved.

Opportunities for S&T bilateral cooperation are expanding as a result of the globalization of science, referred to above, even though Brazil's universities and publicly supported research institutions have been hard pressed as a result of the budgetary crisis in the government. The area of manufacturing technology, where the Japanese have taken the IMS initiative and many industrialized nations, including the United States participate is one example. Another is the environment, where Usaid, has projects in 90 countries at a level of more than US\$400 million per year. Projects concerning forest fires, for example, have been underway with Brazil. The United States Global Climate Change Program is budgeted at over US\$1 billion per year, and includes a major investment in data analysis and distribution. The Earth Observations Satellite Data Information System (Eosdis), initially a Nasa system for handling the huge volumes of data from satellite instrumentation, is being seen as a network whose reach is international with researchers and policy analysts in other nations invited to participate.

In the field of basic science the costs of major facilities — telescopes, space craft, oceanographic vessels, high energy physics accelerators, and the like — has so outrun the resources of single nations that there are strong pressures to internationalize their planning, finance, and management. Even the United States is no longer able to build the world's leading facilities at its own expense and offer them to visiting scientists from around the world as had been the case in the past. This lesson is being learned painfully in the case of the Superconducting Supercollider project (SSC). This high energy physics project was originally intended to be funded by the United States, and other nations were not invited to participate in its design and planning. When the costs rose to some US\$8 billion, the United States approached Japan and other nations, asking for cost sharing. This request has effectively been rebuffed.

It was noted above that the United States Department of State has not accorded a high priority to science and technology matters in recent years. It is

also true that the United States has been a difficult partner in international cooperative projects. As the Carnegie Commission on Science, Technology, and Government put it, "The United States must work to improve its reputation as a reliable partner in international environmental efforts (...)"¹⁰⁴ There are two primary problems: annual appropriations which put continuation of financial commitments at risk and the lack of a coherent policy toward international scientific cooperation.¹⁰⁵

Informatics and intellectual property rights

Information policy has emerged again as a major element of federal policy toward science and technology. The United States played a leadership role in the OECD in information policy in the early seventies.¹⁰⁶ But shortly thereafter informatics lost its place on the policy agenda, and efforts that had been led by the White House were pushed down to agencies, which received little encouragement. This trend has been reversed, in large measure because of the power of computer networks to create markets for information services, to enhance communications and collaboration, and to allow the sharing of scarce resources, specifically the federally sponsored "supercomputer" centers.

An important international S&T facility is the Internet, now a global computer network facilitating remote access to sources of technical knowledge and facilitating remote collaboration. Internet is the largest collection of interconnected networks in the world — a collection of over 4 thousand networks among which electronic mail messages flow. In 1992, 107 countries were connected directly or indirectly to the Internet.¹⁰⁷ Anthony Rutkowski estimates that at least 10 million people have access to the Internet worldwide, and the traffic level in 1992 was growing at over 10 per cent per month. In the United States some 28 million personal computers, or 56 per cent of all PCs installed in the country, will be attached to others through local area networks (LANs) by the end of 1995.¹⁰⁸ Many if not most can be expected to be attached to the Internet. The spread of networks around the world can accelerate developing

¹⁰⁴ Carnegie Commission on Science, Technology and Government. *Environmental research and development: strengthening the federal infrastructure*. New York, Carnegie Commission, Dec. 1992. p. 96.

¹⁰⁵ Keynan, Alexander. The United States as a partner in scientific and technological cooperation: some perspectives from across the Atlantic. (Consultant report to the Carnegie Commission on Science, Technology and Government, June 1991.)

¹⁰⁶ Branscomb, L. M.; Piganiol, Pierre; Balke, S.; Hamada, S.; Hookway, H. T. & Whitehead, J. R. *Information for a changing society: some policy considerations*. Paris, OECD, 1971.

¹⁰⁷ Landweber, Larry. International connectivity. *Internet Society News*, 1(1): 3, Jan. 1992.

¹⁰⁸ Forrester Research's *Network strategy report: LANs for free?* Nov. 1991.

country access to the world's knowledge resources. At the same time, because the information infrastructure of many developing countries is often weak, their ability to take advantage of the global networks is limited.

In December 1991 the Congress passed the High Performance Computing and Communications Act, which authorizes the evolution of the Internet into a broadband, switched network connecting many networks together and serving the needs of education and research. This is the National Research and Education Network (NREN).¹⁰⁹

Senator Albert Gore, Jr., was the champion for this legislation. Having been elected vice-president, he is almost certain to continue to give information technology in general and NREN in particular a high priority in the administration.

Information technology brings certain unique policy issues into play, most especially issues concerning intellectual property. The United States position on intellectual property has been to press for reciprocal treatment in every country that enjoys IP rights in the United States. This issue is increasingly a source of friction between North and South. It is likely to continue to be a source of friction because of the growing importance of IP in the informatics and service industries, worldwide. In addition, there are pressures on the United States to move away from its "first to invent" patent system, and internal concerns about the awkward fit of computer software to either patent law or copyright.¹¹⁰

Global and domestic environment issues

The election of Albert Gore, Jr. as vice-president clearly portends a major shift in United States policy on the environment. President Clinton's fiscal conservatism will limit the public funds that can be invested in measures to reduce the rate of injection into the atmosphere of greenhouse gases and to find accommodation with the developing nations for global sustainable development. Where President Bush held back on support for the UnCED in Rio de Janeiro, and attended the Rio conference only briefly, Senator Gore was present and active in his support of the conference goals.

President Clinton has delegated to the vice-president responsibility for science and technology policy coordination. Vice-president Gore will certainly include environment in that scope, for he hand-picked both the administrator of

¹⁰⁹ Branscomb, Lewis M. Information infrastructure: a public policy perspective. In: Kahin, Brian (ed.). *Building information infrastructure: issues in the development of the national research and education network*. New York, McGraw-Hill, Dec., 1991.

¹¹⁰ Computer Science and Telecommunications Board, National Research Council. *Intellectual property issues in software*. Washington D.C., National Academy Press, 1991. p. 111. (L.M. Branscomb chaired this study team and workshop.)

the EPA (a former staff member to Senator Gore and more recently director of the Florida EPA), as well as the science advisor. As noted above, global change research will continue to receive strong government support in the United States, and the Global Change Data and Information System is being designed to encourage other nations to participate in it, using the international services of the Internet.

Shifts in environment policy can be discerned of four kinds:

— President Bush's "no regrets" policy on global climate change rested on the assumption that no action would be taken to reduce carbon consumption unless it was justified by other necessities, such as oil import reduction or air pollution. Thus if global warming proved to be illusory, there would be "no regrets" over costs needlessly incurred reducing greenhouse gases. The Clinton-Gore administration is more likely to seek a middle course, with early steps to reduce atmospheric CO₂ production, through an oil import tax or a gasoline tax, or both.

— Transnational and global environmental impacts are becoming a much larger part of the international affairs agenda in governments rich and poor. With the election of Clinton and Gore it is likely that the United States government will take a much more activist position than the Reagan and Bush administrations have done, as evidenced by the United States positions at the Rio Conference.

— Most large manufacturing firms face major environmental costs and risks, and no longer treat environment as simply a public relations and regulatory issue; it has become a part of mainstream business strategy. This is leading to technical efforts to modify industrial processes to minimize those risks and costs, and to pressures on government to modify the regulatory regime to encourage this process approach, instead of focusing regulations on technologies to remove pollutants from process outputs.

— Government is beginning to experiment with market surrogate mechanisms, such as tradable permits for emitting pollutants, in order to improve both the incentives on industry and the efficiency of the regulatory process. The 1991 Clean Air Act includes such provisions. This policy direction provides enhanced incentives for private efforts; its advocates believe it will lower costs of meeting environmental goals. The United States will probably urge other nations to follow this policy direction.

— Political leaders are beginning to react to Japanese and German government actions to promote the development of "green" production technologies and equipment as a strategy for building an environment export market to reduced

domestic economic cost of environmental compliance. Similar R&D investments by government may be seen in the United States in the future. The possibility of sharing such "green" technologies with developing countries as part of an overall North-South accommodation on global climate change and other trans-border environmental effects will doubtless be discussed as such programs develop.

In summary: the new administration will be much more willing to discuss constraints on greenhouse gas emissions in international venues than was President Bush, but President Clinton's fiscal conservatism and commitment to reduce the federal deficit will not allow a major concessional assistance program to the South in return for constraints on coal and wood burning or deforestation.

Energy and non-proliferation

The Department of Energy will continue to be absorbed in environmental remediation of its nuclear facilities, for which total cost of over US\$100 billion is estimated over a period of years. With the political transformation of the former Soviet Union, the rising number of nations apparently seeking a nuclear weapons capability, and a dramatic rise in regional conflicts, non-proliferation will be high on the administration agenda and will color its attitude toward nuclear fuels and reprocessing. Brazil experienced serious friction with the Carter administration over this issue, but the return of Democrats to power does not signal a similar level of policy conflict with Brazil, if Brazil ratifies the agreement to accept the IAEA safeguards signed by Brazil and Argentina in December 1991.

A second concern will be the downsizing of its nuclear weapons establishment, as noted in the section on national laboratories. This second effort will, however, give the department incentives to look for energy-related technology activities. The Energy Department will be pushing hard for alternative fuels for automobiles, but will probably be more skeptical of the virtues of ethanol than was the Bush administration. It is likely that a gasoline tax will be levied, to bring revenue to the treasury and provide incentive for conservation. The administration will also press forward with their project to develop a practical battery for powering electric or hybrid gasoline-electric cars. Given Brazil's extensive experience with ethanol-powered vehicles, and at the same time Brazil's new source of hydroelectric power, a cooperative United States — Brazil project evaluating the prospects for both electric and alternative hydrocarbon fueled cars might be attractive to both countries.

9. "Megaprojects" and technology demonstrations

One of the conspicuous failures of government management, which might be alleviated with the right process of evaluation, is the technical "mega-project". Linda Cohen and Roger Noll have studied six cases of such projects, each intended to accelerate the commercialization of a capital intensive technology.¹¹¹ Among their cases were the supersonic transport aircraft, the Clinch River breeder reactor, a coal gasification project, and the solar photovoltaic program. In each case a nominally attractive economic case was in hand at the beginning of the project, but the project was soon captured by constituencies that lobbied for it and benefitted from it. When either the market or the technology changed, the political environment prevented the project from adapting to new circumstances. As they became conspicuously uneconomic, political justifications were invoked and kept most of the projects alive long after any utility remained.

The normal program planning, review, and resource allocation process is not sufficiently robust to contain such projects within sound limits. What is needed is a requirement, embodied in the authorizing legislation, that the economic and market assumptions on which such projects are based are rendered explicit, and that the goals and the implementation plans be exposed to external as well as internal analysis and review. This external evaluation should be repeated at defined intervals, and the process and its conclusions made public. What institutional structure might perform such reviews? One solution is to charter the National Academy of Engineering to create a panel for each project, funded to subcontract the analytical work to professionally qualified institutions. The final decisions would be made in government, presumably in the OMB, of course, but the fact that the evaluation is external to government will protect the evaluation from the political conflict of interest inherent in the administration's responsibility for managing it.

10. Science advice and S&T decision making

"Taxonomy" of United States science advisory functions, activities, and institutions

At least 10 kinds of government functions are supported by formal institutional structures for the provision of outside scientific and technical advice (table 5).

¹¹¹ Cohen, Linda R. & Noll, Roger G. *The technology pork barrel*. Washington D.C., The Brookings Institution, 1991.

Table 5
"Taxonomy" of U.S. science advisory functions

Advisory function	Example
High level policy: setting political agendas	PCAST: advises president
Technology assessment: socio-technical agendas	OTA: advises Congress
Regulatory processes: statutory advisory committees	RAC: advises the FDA
Procurement strategies, resource allocation	Peer review panels
Program management: tracking specific programs	IVHS America: advises Dept. Transportation
Policy analysis: support for executive agencies	NRC: advises all agencies
Policy support: program evaluation, planning	DSB: advises Sec Defense
Institutional performance: evaluation committees for laboratories and other institutions	NRC Review Panels for Nist
Part time governing boards, limited decision authority	NSB: governs NSF
One off commissions for special topics	President's Commission on Productivity

The executive branch

At the highest levels of government there are boards of citizen-experts who provide general policy advice, in addition to considering specific issues put to them by government officials. President Bush met regularly with his President's Council of Advisors on Science and Technology (PCAST). This distinguished group of scientists and engineers, drawn from both academic and business experience, was led by the President's Assistant for Science and Technology and represents the apex of science advice to the executive branch of government. The PCAST is not required by statute, however, and there is no certainty that President-elect Clinton will appoint such an advisory body. The scientific community will apply pressure to have him do so. This high level advisory committee both legitimates the administration's actions in science policy, and legitimates the President's Science Advisor in the eyes of the scientific community.¹¹²

¹¹² Golden, William (ed.). *Science and technology advice to the President, Congress, and Judiciary*. New York, Pergamon Press, 1988; Golden, William (ed.). *Science advice to the President*. New York, Pergamon Press, 1980.

Most of the executive departments also have high level boards of science and technology advisers and a myriad of more specialized advisory committees throughout their agencies. The Defense Science Board gives both solicited and unsolicited advice to the Office of the Secretary of Defense. The statute establishing the National Institute for Standards and Technology (Nist) requires the appointment of a Statutory Advisory Committee to assess this agency's performance and to call to the attention of the Secretary of Commerce any policy issues that concern the committee members.¹¹³

Federal regulatory agencies setting mandatory limits or providing product approvals to protect the environment and public health and safety also have a variety of advisory bodies, some statutory, to review proposed agency regulations and to advise on agency research, processes and technical assessments.¹¹⁴ An explosion of new agencies, each with associated advisory mechanisms, occurred in the early seventies. EPA was established in 1970. It created a Science Advisory Board in 1974, which was given statutory permanence in 1978. The 1977 Clean Air Act amendments required establishment of the Clean Air Scientific Advisory Committee to review the science underlying proposed standards. In 1975 a Science Advisory Panel was created to review proposed pesticide regulations. A similar array of advisory bodies sprang up in the Food and Drug Administration (FDA), the Department of Agriculture, and in many other regulatory agencies.

The Congress

The Congress has its own institutions for providing scientific and technological early warning and advice. Best known is the Office of Technology Assessment (OTA) whose studies are commissioned by bipartisan agreement of Congressional committees. Science and technology policy advice is also provided by the Library of Congress' Congressional Research Service (CRS) and the General Accounting Office (GAO). The Science Policy Division of the CRS provides quick response to Congressional requests, and the GAO's studies stem primarily from its responsibility to audit the executive agencies' stewardship of their Congressional authority. The OTA is notable among advisory bodies in the federal government in that it engages in studies in considerable depth, often requiring a year or more to complete, and conducted under a bipartisan charter. While its reports cannot be said to be free of political content, they provide analysis of

¹¹³ This committee, chaired by Mervin J. Kelly, president of Bell Telephone Laboratories, played a critical role in the resolution of a bitter controversy over the handling of the "Battery Additive AD-X2" case in 1953. U.S. Congressional House Committee on Science and Technology. *Technical information for Congress*. Washington D.C., Government Printing Office, Jul. 1979. pp. 23-69.

¹¹⁴ Jasanoff, Sheila. *The fifth branch: science advisors as policymakers*. Cambridge MA, Harvard University Press, 1990.

alternative policies rather than making actionable recommendations. The primary source of Congressional advice on science and technology is, of course, invited testimony from both experts and advocates in public hearings conducted by the committees and in studies commissioned directly by the Congress. There is no institution in the executive branch comparable to the OTA.

Enhancing the ability of Congress to deal more effectively with the scientific and technological content of the issues before it is a quite different matter from addressing the problem in the executive branch. The Congressional process has been addressed by two studies made by the Carnegie Commission on Science, Technology, and Government¹¹⁵ under the leadership of John Brademas, which recommended the formation of a Congressional Study Group on Science and Technology, through which more effective ways to deal with scientifically complex issues might be explored.

The quasi-governmental sector: national academies of science and engineering

Perhaps the most impressive (in scale, variety, and level of expertise) source of advice for federal agencies and the Congress is the National Research Council (NRC), Congressionally chartered in 1918 at the request of President Woodrow Wilson to provide expert advice to the federal government on matters of science and technology. The NRC is managed by the National Academy of Sciences (and its sister bodies the National Academy of Engineering and the Institute of Medicine), which itself was chartered to advise the government in 1863.¹¹⁶ In response to agency and Congressional requests, the NRC performs studies engaging annually the volunteer services of 9,500 experts. On 60 occasions in the last five years the Congress has mandated NRC studies, resulting in Congressional testimony on 200 occasions during this period.¹¹⁷ The NRC is certainly the single most active source of outside advice to the government on scientific matters, and it comes closest to representing the technocratic approach, in which as far as possible scientists give advice devoid of conclusions as to the political implications of its conclusions. However, the NRC panels have become more astute about understanding the polit-

¹¹⁵ Carnegie Commission on Science, Technology, and Government. *Science, technology, and Congress*. Part I: Analysis and advice from the Congressional support agencies. Part II: Expert advice and the decision-making process. New York, Carnegie Commission, Feb. 1991.

¹¹⁶ The Act to Incorporate the National Academy of Sciences of March 3, 1863, specifies that the Academy "(...) shall, whenever called upon by any department of the government, investigate, examine, experiment, and report upon any subject of science or art (...)" It further provides for the expenses of such advice to be defrayed by the requesting agency, but provides that "(...) the Academy shall receive no compensation whatever for any services to the government of the United States". Thus all members of advisory panels serve without compensation.

¹¹⁷ This information was provided by Dr. Philip M. Smith, executive officer of the NRC Governing Board, Feb. 7, 1992.

ical context of their work. The result, however, is that many NRC studies frustrate the Congress' desire to come to grips with the political issues.

Shortcomings and suggestions for institutional improvements

1. High level science and technology perspectives are inadequately present in policy determinations where the issues are not seen as primarily technical.
2. High level science and technology advice to the executive branch does not effectively address long term issues of broad technical scope, especially when the government's objectives are not clear nor strongly publicly supported.
3. Advice on sustaining the vitality of the United States science and engineering enterprise becomes suspect when it comes from self-serving advisory bodies addressing the needs of their own community.
4. The utility of science and technology advice requires that expert advisers achieve technical and political legitimacy, which, in turn, legitimates the functions of the government bureaucracy. In a democracy the legitimacy of "experts" is always subject to question.
5. How can science and technology advice contribute to informed and rational self-government in a world of increasing technical complexity? How, in fact, is legitimacy to be achieved? This is a question that must be explored if we are to understand the role of science advice in the United States political system.

We must look to the nature of the American version of the modern democratic State, which not only requires access to expert knowledge for conducting the affairs of government, but requires a sufficient degree of legitimacy for the decisions of government to justify the continued delegation of power from the electorate. In this respect the nature of American politics seems to be very different from that of many other democratic States, especially as it regards the behavior of politicians and the roles of elites.

Yaron Ezrahi¹¹⁸ advances the thesis that the founders of the new American nation saw science as a cultural model which validates the idea that witnessing the instrumental exercise of public responsibilities satisfies the normative goals of the citizenry. Ezrahi emphasizes the empirical, practical, experimental approach we normally associate with American culture. Because Americans

¹¹⁸ Ezrahi, Yaron, *The descent of Icarus: science and the transformation of contemporary democracy*. Cambridge, Harvard University Press, 1990.

reject the delegation of authority to a self-selected elite to make decisions on complex matters in our behalf, he argues, they insist on judging officials by their actions. Science becomes the paradigm for the source of public knowledge and order, and of authority legitimated by informed, voluntary consent. Thus science is used to depoliticize politics.

"The physicians, physicists, chemists, engineers, economists, psychologists, and other professionals who are massively deployed at all levels of government action in the modern democratic State help institutional instrumentalism not only as a substantive mode of action but perhaps even more as a political strategy for constructing, legitimating, and criticizing public action."¹¹⁹

The deficiencies of provisions for incorporating the advice of technical experts into the formulation of public policy in the United States have much more to do with process than with organizational structure. The key problem is the accommodation of the cultures of science and of politics in ways that preserve the values inherent in their differences as well as dealing with their interdependence. Even more fundamental is the nature of the public institutions for conducting the public's business and the quality and motivations of the managers and politicians in charge. No institutional mechanism for advising a president can overcome the president's disinterest; no president desirous of independent advice on a scientific matter will have difficulty satisfying his need. But well constructed and managed advisory bodies can not only help the nation take advantage of the knowledge available to its citizens, but can help empower those citizens to hold their public representatives accountable and strengthen democracy.

11. Indirect policies

This paper has focused on federal activities in generation and diffusion of technology through support of technical operations. There are also indirect policies to enhance technical performance of the private sector. Most proposals for indirect policy fall into the sphere of macroeconomics: efforts to reduce the cost of capital, to induce investment in plant and equipment through investment tax credits, to create equity capital through reduction in long term capital gains, and to encourage increased R&D investment through R&D tax credits. All of these policies have the effect of aggravating an already serious federal deficit, which limits their attractiveness as tools for dealing with industrial competitiveness. The direct policies have two advantages: most are targeted to activities selected

¹¹⁹ Ezrahi. Loc. cit. p. 38.

for their effectiveness, and most can be funded by shifts in investment from defense to non-defense purposes.

Both President Bush and Governor Clinton endorsed making permanent the incremental R&D tax credit. Congress has been extending this tax credit year by year, and proponents of making the credit permanent argue that uncertainty about future tax benefits deprives this tax credit of much of its power to motivate increased R&D investment.

12. The Clinton-Gore technology policy: current issues

The Clinton-Gore campaign paper on technology policy promises to renew the civilian technology base, shifting the balance between defense and non-defense federal R&D from 60:40 to 50:50. The policy paper features six broad initiatives:

- "1. Investing in 21st century infrastructure [including a digital, broadband communication system called the Information Network System].
2. Establishing education and training programs for a high-skills work force.
3. Investing in technology programs that empower America's small businesses.
4. Refocusing federal R&D programs on critical technologies that enhance industrial performance.
5. Leveraging the national R&D investment.
6. Creating a world-class business environment for private sector investment and innovation."¹²⁰

A significant decision by President-elect Clinton is to entrust to the Vice-president Albert Gore, Jr. "the responsibility and authority to coordinate the administration's vision for technology and lead all government agencies, including research groups, in aligning with that vision". The statement goes on to say:

"The vice-president will take on the task of organizing all facets of government to develop and implement my administration's technology policy. As a first step, he will establish a central focus for the coordination of government activities

¹²⁰ Clinton-Gore. *Technology: the engine of economic growth: a national technology policy for America*. Little Rock, Arkansas, Clinton-Gore National Campaign Headquarters, Sept. 21, 1992.

related to civilian technology and create a forum for systematic private sector input into United States government deliberations about technology policy and competitiveness."¹²¹

On reading this statement, it is unclear what the role of OSTP is intended to be, for by law it is the "central focus for the coordination of government activities in (...) technology". It is unclear, as of early January 1993, whether technology will be more visible on the White House agenda, with the vice-president assuring that S&T issues reach the president's attention, or whether the effect will be to isolate technology as a political issue in the vice-president's Office, weaken OSTP, and reduce the effective access to the president of the director of OSTP (who serves also as Assistant to the President for Science and Technology). One favorable early sign is that for the first time in 16 years the incoming president has nominated his science advisor prior to inauguration. Dr. John Gibbons, director of the Congressional Office of Technology Assessment and a nuclear physicist with a strong environmental background, has been named for this post. His credentials as a policy analyst for science and technology issues is unchallenged.

13. Current issues and conclusions

It is likely that the emphasis on lists of critical technologies is a transient event in United States technology policy, although the language is surely here to stay. If new policies are to be implemented, they must be clearly stated, with objective criteria for project selection and evaluation, and related to stated goals. On the other hand, so long as governments go beyond basic research in attempts to provide a knowledge environment supportive of a competitive, expanding economy, they will have to define policies that:

- (a) differentiate the government's role from that of private investors and entrepreneurs; and
- (b) set priorities for government investments in civilian technology.

The idea that programs meriting priority will be called "critical", will sooner or later have to give way to the reality that the government's role is not defined by "criticality" but by the underinvestment by private firms in knowledge with large positive externalities. Just as one would not call government funding of basic research in low temperature physics "critical" to national well-being, the association of "critical" with "generic" will become increasingly inappropriate.

¹²¹ Clinton-Gore. Loc. cit. p. 8.

Signs that the policy debate is becoming more sophisticated are at hand. The American Technology and Competitiveness Act of 1992, sent forward to the House of Representatives by the Committee on Science, Space, and Technology in the Summer of 1992¹²² has a title III entitled Critical Technologies. It focuses, however, not on the identification of "critical technologies" but on mechanisms to coordinate the development of a national policy, the implementation of which will ensure United States leadership in technologies (and their applications) "essential for industrial productivity, economic growth, and national security (...)"

The work on priority setting for federal R&D, already launched by the Subcommittee on Research of the House Committee on Science, Space, and Technology, will see the development of clearer, more appropriate language in this area. The need for competitive and comparative assessment of United States industrial technology is clear. The distinction between the use of export controls and export promotion should reduce the danger of confusion. Finally, the need to focus on the appropriateness of federal expenditures, and not just on priorities for choosing technical areas should become apparent.

Perhaps the best explanation for the emergence of critical technology studies is the recognition that government missions have defined technology priorities in the past, and a new way to set priorities in support of economic health must be evolved. Critical technologies — as a concept without policy relevant criteria — is not up to the task.

There are five primary obstacles to consensus on technology policy as it relates to the civil economy:

(a) lack of crisp, robust criteria to delimit the federal role in each of the program types devoted to commercial technology;

(b) concern that the discipline of such criteria will be corrupted politically, the primary reason many conservatives oppose an active technology policy;¹²³

(c) lack of confidence in the ability to build government institutions with the competence and the latitude to make judgements — a view that deprives agencies of legitimacy;

(d) confusion about direct foreign investment and how to deal with United States firms that are subsidiaries of foreign corporations, and the overseas subsidiaries of United States headquartered firms;

¹²² H.R. 5231.

¹²³ Wiedenbaum, Murray. Testimony before the Joint Economic Committee of the Congress, Sept. 12, 1991.

(e) lack of strong constituency for the kind of decentralized program of technical investment that has difficulty competing with the concentrated spending of megaprojects.

One obstacle to consensus on technology policy is the question most often posed by economists: what proof have you that United States industry is in technological decline, requiring government intervention? This is coupled with a question asked by conservatives, including many business people: what proof have you that the government has the competence to help, even if such help were indicated?

To the first question: it does not matter. In fact, there are many signs of resurgence of United States manufacturing competitiveness. Even the merchant semiconductor industry has reversed its loss of world market share, and is showing a small gain. The United States government should be helping to enhance the comparative advantage of its institutions and people either way. Indeed, it is more likely that government R&D will be useful if industry is optimistic and is investing for the future, than if it is cutting costs, reducing R&D and laying off people.

To the second question: strategic technological assistance to save a hard-pressed segment of industry will usually face a poor prognosis. But the United States government has demonstrated for 40 years the ability to create basic science for the world, and technology for its own missions, through the very kind of decentralized, merit-based, competitive programs that are needed for pathbreaking and infrastructural technologies. It needs only update its conception of public goods, to include those two categories of technology, and develop the required cooperation from the technical expert in industry to help manage the new programs.

There remains this question: what constituency will support the emerging technology policies and shield the politicians from the heat of criticism when conflicts arise, as surely they will?

Only the business community, supported by labor and the technical community, can provide legitimacy and effectiveness to technology policy. Business leaders must articulate the economic and political philosophy that allows a role for government in the encouragement of path breaking and infrastructural technologies. If they do, political leaders will follow their lead. Here one must be impressed by the consistent support for a well-constructed federal program of investment with the private sector in technology infrastructure. The National Association of Manufacturers, the Council on Competitiveness, the Computer Systems Policy Project and trade groups such as the American Electronics Association and the Aerospace Industries Association are consistent in their call for a more methodical and managed effort to enhance the technical comparative advantage of United States firms.

How might government be organized to carry out such a policy? The most obvious assignments are as follows:

Figure 3
Restructuring government for United States technology policy

— State governments: federalism in economic/technology policy.

Operational initiative in diffusion policy.
Abate destructive competition for foreign investment.
Consensus on treatment of foreign ownership.

— Commerce Department lead agency role for civil technology.

Build constituency and industrially experienced leadership.
Recreate advisory structure for private sector input.
Nist as primary operating agency for civil technology policy.

— New roles for Defense and DOE weapons laboratories.

Rebuild acquisition policies and regulations.
Reemphasize long-range R&D role.
Downsize where missions are shrinking.

— New roles for Energy and Environment Departments.

Energy Department has vast R&D resources, shrinking mission.
EPA is a regulatory agency; environment needs technology development and environmental science associated with regulatory function.
Suggests combining into new Department of Energy and Environment.

— Need for coherent policy development and management in the Executive Office of the President.

OSTP-CEA-NSC supported by FCCSET and the Critical Technologies Institute.¹²⁴ The critical near term question is the role of the vice-president.

I draw six conclusions:

(a) even as nations experiment with new paradigms for industrial policy, the relationship of science to engineering and the ways science and engineering are used by industrial competitors are changing rapidly;

(b) public policies for enhancing the technological dimensions of competitiveness, and the assumptions underlying these policies, have quite different histories and different priorities in Europe, North America, and East Asia;

¹²⁴ OSTP: Office of Science and Technology Policy; CEA: Council of Economic Advisors; NSC: National Security Council; FCCSET: Federal Coordinating Council for Science, Engineering, and Technology.

(c) these policies are still evolving in all three regions of developed industrial economies, but are beginning to come together as all industrialized nations face similar challenges and opportunities;

(d) the trend is increasingly toward private initiative and private resources, in industrialized, former socialist, and developing economies, reducing the direct influence of governments;

(e) the new policies will call for much more sophisticated capabilities in government, and the economic health of the world will, paradoxically, depend even more on wise government policies, even as government action becomes more limited in scope and more restrained in nature;

(f) the primary challenge will not be the relationship of government and private efforts within each of the three industrialized areas, but the need to preserve an open environment for economic and technological alliances across area boundaries and to bring other economies, especially the newly-developing and former socialist countries into this vibrant world community of cooperating and competing nations.

In conclusion: with the election of Governor Clinton as president, the nation has endorsed placing priority on domestic economic concerns. Initially this will probably have the effect of drawing attention away from the international dimensions of science and technology policy. However, the previous administration's foreign policy focus was not on trade, science cooperation, and other relationships with United States trading partners in the hemisphere. It was clearly focused on the USSR and the attempt to neutralize Soviet influence around the world. Today the United States is in a State of rapid policy change, as indeed Brazil may be. This rate of change will soon begin to slow, and the United States government will have the opportunity for innovation in the field of foreign relations. Given the strong international interdependence of science and technology, and the important place that foreign trade plays in the economies of both countries, it is likely that the climate will quickly improve for stronger United States-Brazilian relationships.

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Performance, specialization and international integration of science in Brazil: changes and comparisons with other Latin American countries and Israel

Thomas Schott*

Acknowledgments

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National scientific development and participation in world science

Throughout history people have interpreted sensed phenomena, and their interpretations have fueled intellectual traditions within many civilizations. Typically, a tradition has been parochial insofar as its cultivators have not been interested in extending participation, and even if they occasionally have sought to extend participation, it has remained a local endeavor because people in other civilizations aware of the exogenous tradition have refrained from participating in it (Shils, 1981).

Science, however, is an atypical tradition in its extensive communality. Present-day participation in the scientific tradition is worldwide. Not only is science practiced in every society but its practitioners are receptive to ideas from any place on earth, pursue long-distance collegial ties, and disseminate their creations globally. This globality has evolved only recently. Until the 19th century, the tradition was concentrated within one area, Europe, where it had become established just a few centuries earlier. Global participation emerged in the 20th century. The formation of a global communal endeavor was a process of institution-building: both institutionalization, that is, granting legitimacy, appreciation and autonomy, and establishing institutional arrangements for global communal participation.

* Department of Sociology, University of Pittsburgh.

In early 17th century Europe, the pursuit of knowledge about natural phenomena had some legitimacy and some appreciation but little autonomy. It was controlled by political and ecclesiastical authorities who respected religious dogma over natural knowledge. But a social movement had formed in Europe which was inspired by an utopian faith in progress by advancing empirical knowledge applicable to controlling and exploiting nature. This scientific movement advocated legitimation for the search for truth through empirical inquiry as an activity worthy of cultivation. The movement was successful first in England in the middle of the 17th century. The movement won legitimation for science as an intellectual tradition cognitively distinguishable from intellectual traditions such as contemplative philosophy, practical arts, crafts and religious thought. The shift to a considerable appreciation for empirical inquiry into God's creations, especially nature, was triggered by Puritan thought (see the content analysis of Puritan statements by Merton, [1938] 1970, chap. 4-5). But the enhanced appreciation was broad as evidenced by the participation in science of not only Puritans but also many people from diverse other faiths (Merton, [1938] 1970, chap. 6, shows the high participation of Puritans, and the high participation from diverse other faiths is shown in many studies; whether Puritans were overrepresented is debated but not crucial here where the documented great diversity of participation is the relevant evidence showing the breadth of the appreciation of natural inquiry). Political and religious authorities granted natural inquiry considerable autonomy and authority as a source of truth along with the Bible. This institutionalization in England was imitated in the continental societies that in the culturally well-connected but politically decentralized Europe were competing for national esteem through appreciated cultural forms (Ben-David, [1971] 1984: 75-87; Greenfeld, 1987; Wuthnow, 1987: 265-98). Empirical inquiry became appreciated as worthy of pursuit and support, it was granted autonomy from control by other spheres, and it was differentiated from other activities by establishing organizational arrangements specifically for this endeavor. These arrangements included the separation of a dignified social role or vocation devoted to empirical inquiry and organizational arrangements for formulating and implementing policies shaping the endeavor, for recruiting and training incumbents of the new social role, for validating claims to knowledge and disseminating knowledge, for evaluating and rewarding role-performance, for promoting and regulating communication and other role-relations, and, more generally, arrangements for integrating the practitioners into a community with a self-organization spanning across long distances, across nations, religions and other social divisions. This differentiated tradition became coined *science* and the social role became coined *scientist*. Science became supported by the provision of social resources such as laboratories, apparatus, libraries, and livelihood of the incumbents of the new role. Many of the scientists were employed as teachers in universities and in the 19th century scientific research became adopted as another purpose of many universities, along with teaching, especially in Germany. Although the scientific

role became anchored on universities, hospitals, museums and other organizations, science continued to be practiced as a communal enterprise. The establishment of distinctiveness, legitimation and autonomy for the pursuit of science is commonly referred to as the institutionalization of science (Ben-David, [1971] 1984).

This first institutionalization occurred mainly in Northwestern and Central Europe but less extensively on the Iberian Peninsula and elsewhere. Institutionalization was then extended to the European settler-societies around the world, notably in North America, Australia and in what became Israel, but it did not extend much beyond the boundaries of Western civilization. There was little institutionalization of science on the Iberian Peninsula and therefore institutionalization did not extend to the colonies in Latin America (Schwartzman 1991: chap. 2-3). Despite the boundedness of the scientific movement within Europe, the institutionalization of science had a potential for expansion.

The institutionalization of science in Europe codified a conception of nature as invariant in time and place. Knowledge was conceived to have a truth value independent of the researcher and therefore have the same truthfulness in all civilizations. The participants were recognized and considered themselves as discoverers of truth. Knowledge was considered to be cumulative and to be a component in the broader vision of human progress as an ongoing advancement of humanity. The doctrine of progress of humanity as an imagined global civilization promoted a cosmopolitan orientation among the participants (Anderson, 1983; Robertson, 1992; Schott, 1993b, forthcoming). Natural inquiry was to be open to participation from any part of mankind (extended later to include women), and the resulting knowledge was to be widely disseminated as a collective good of humanity. This cosmopolitan orientation sustained knowledge diffusion and collegial ties across social divisions and long distances (Daston, 1991). The faith in invariance of nature and in truthfulness of knowledge across places, together with the cosmopolitan orientation of the participants, created a potential for adoption of the European tradition in the non-Western civilizations.

The non-Western civilizations encountered European civilization mainly through its military, political, economic, and religious expansion. European intruders were not interested in imposing the European scientific tradition on indigenous peoples, but brought local people into contact with European goods and equipment; systems of communication, transportation, extraction, and production; and means for curing diseases and conducting warfare. Some local people considered European techniques better than their own and therefore judged European knowledge worth obtaining. Their efforts to import that knowledge promoted interest in participating in the creation of such knowledge, especially when some went to study at universities in Europe where they acquired a taste for research and upon their return home advocated establishing scientific organizations. This local legitimation and appreciation for science led to some autonomy for efforts to assimilate the tradition from the West (Adas, 1989, 1991; Altbach &

Selvaratnam, 1989; Eisemon & Davis, 1991; Petitjean; Jami & Moulin, 1992; Shils, 1976, 1991). The adoption of the scientific tradition seems to have preceded the adoption of other Western traditions such as the ideology of human progress and rationalization. The institutionalization proceeded, albeit with fragility and frequent moves toward deinstitutionalization, mainly around the 19th century in the non-colonial societies and also in the colonial societies, despite many colonizers' opposition. Institutionalization was one step of institution-building; the other step was to establish social arrangements for practicing science.

The institutionalization was accompanied by establishing institutional arrangements comprising a specific social role or vocation for science, organizations for housing the scientific role, and arrangements for mobilizing needed social resources. Such arrangements, established in every society, are strikingly similar around the world. The similarity of institutional arrangements can be explained by their common source in world standards, both model arrangements diffusing through the web of scientists from center to periphery and doctrines promulgated by a global science policy regime.

Over the centuries scientific ideas and institutional arrangements have diffused from a center, located where scientists have recognized the greatest accomplishment (Ben-David, [1971] 1984; Shils, [1961] 1972a, [1961] 1972b). Scientists have attributed the achievements of the center partly to its institutional arrangements and therefore considered the center arrangements to be especially effective. In addition, their deference toward the achievements created in these institutions have infused a sense of appropriateness in the center arrangements so they have become standards to which adherence is expected. The foreign observers' beliefs in the effectiveness and in the appropriateness of the center arrangements have made them standards for imitation in their home countries (Schott, 1980, 1987b). Notably, non-Western participants regarded Western practitioners of science as role-models and the Western role-definition of a "scientist" became imitated as a new role in the non-Western societies. This role of assimilator-creator-disseminator of knowledge also included a cosmopolitan orientation and an identity as a participant in a communal endeavor transcending traditional civilizational boundaries. Modified by the local social ecology, organizations for the practice of science were likewise established in the non-Western societies as copies of Western organizational forms such as the university and the scientific academy. Mobilization of social resources has been regularized, as in the West, by taxes, by grants and contracts for research, and by combining science with higher education.

Institutional arrangements are established not only by the process of diffusion of center models through the global scientific community, but also by adherence to doctrines promulgated by the global science policy regime, that is, the complex of arrangements shaping science policy around the world (King, 1974; on international regimes in general, see Young, 1989). Science policy, including

doctrines of science and policies for and through science, is increasingly formulated and advocated by a regime sustained by and operating through a network of organizations such as the United Nations Educational, Scientific and Cultural Organization (Unesco), the Organization for Economic Co-operation and Development (OECD), the Rockefeller Foundation, and the World Bank. These scientific doctrines become standards that are adhered to around the world partly because organizations such as Unesco and OECD work through experts in rational organization and acceleration of progress with authority to design and recommend policies and strategies, because organizations such as the Rockefeller Foundation sponsor scientific endeavors selectively around the world, and because organizations such as the World Bank make loans to a state contingent on its policy for science. The scientific doctrines of the global science policy regime are also influential because by adhering to the standards, nation-states and their leaders can enhance their esteem as participants in the emerging global civilization of modernity in which the scientific doctrines are part of the prevailing broad ideology of human progress that is also promulgated by these organizations. Indeed, the global science policy regime is an element of the world-polity (Meyer, 1987; Ramirez, 1987). Science continues to be considered a component of the progress of individuals, nations, and humankind, and there is a widespread belief that such progress can be accelerated by rational organization and mobilization of resources for the pursuit of science. The meaning of human progress, though, is no longer mainly religious, but focuses on social and economic growth, power, and wealth. In mighty and wealthy societies, progress is considered in terms of national security and competitiveness (Hill, 1989), and in poor societies it is concretized in terms of catching-up, development and modernization (Apter, 1974; Sagasti, 1979; Shahidullah, 1991). Thus the rapid growth of scientific activity in virtually all societies since mid-century can be explained as a result of the scientism and the doctrines promulgated by the global science policy regime (Ben-David, 1991: 521-59).

The science policy regime also shapes communal participation. The rational organization of science for national progress is thought to require integration of the national research endeavor with world science. The doctrine against intellectual protectionism, combined with the scientists' cosmopolitanism, counteracts parochialism and enhances participation in communal formations spanning the globe.

Although each scientist knows very few of the other practitioners, they consider themselves cultivators of a collective tradition, forming not only local communities but even a global community (Anderson, 1983). Their sense of intellectual and moral communion is reinforced by their ties across social divisions and long distances and by institutional arrangements such as the Nobel Prize ritual and international scientific meetings and organizations, e.g. the International Council of Scientific Unions, and the agreement on free dissemination of scientific literature, an international agreement that is vital. The global scientific com-

munity of all scientists is informally organized into a global web of collegial ties. Between the macro-level of the global scientific community and the micro-level of the individual scientist are numerous intermediate groupings. The kinds of groupings commonly examined are a Kuhnian community of specialists, a research team, the scientists in an organization, and those in a country (reviewed by Shrum & Mullins, 1988). Specialization, membership in a research team, organizational affiliation and societal location are groupings that all shape the web of ties among scientists (e.g. Schott, 1987a; Shrum, 1985). For understanding national participation in science, an especially significant grouping is the national scientific community. The national scientific community of the scientists in a country is informally organized by the web of their ties with one another and with foreign colleagues. Their foreign ties shape national participation in world science. Individual participation in world science can be described by the concept of a social circle consisting of a scientist's web of collegial ties with the local and distant peers who are significant for the scientist's work. These individual, national, and global webs are nested: a scientist's collegial circle is nested in the web of the scientist's national scientific community, which in turn is nested in the global scientific community. These web enable network modeling (Schott, 1991a).

Brazil in regional and peripheral locations

The scientific tradition is being adopted in virtually every society around the world. Science is becoming legitimated and appreciated and practiced with support and backing from the local population or at least from a powerful stratum of the society. Science is being valued variously as an endeavor worthy in itself and variously for its multiple uses in nation-building and national development, and perhaps also as a symbol of modernization signalling participation in the world system of significant societies. Institutional arrangements for scientific activity are typically not local innovations but are usually modeled on arrangements prevailing in the place of highest performance, the center of world science. Scientists from much of the world congregate in the center. They consider the institutional arrangements in the center as most appropriate and also as most efficient insofar as the high performance of the center plausibly can be attributed to its institutional arrangements.

Despite the widespread modeling of the central institutional arrangements, however, there are considerable differences among societies in their institutionalization of science. Institutionalization differs among societies in degree and manner. Societies differ in their appreciation of science, in their granting of autonomy, in their provision of social resources, and in their institutional arrangements for science, and this shapes their scientific activities, including their research performance (Schott, 1987b). Scientific activity in a small national scientific community cannot be self-reliant — not even Soviet research was self-

reliant (Schott, 1992a, 1992b). Local scientific work is more or less integrated with scientific traditions elsewhere, especially in the places of greatest creativity. World science has had its shifting center, the center was in England at time of institutionalization, then moved to France, then to Germany, and since World War II the major center has been in the United States (Ben-David, [1971] 1984), with Western Europe emerging as a secondary center (Schott, 1991b). Scientifically small countries have tended to be peripheries that are attached to and variously integrated with the center (Shils, [1961] 1972a, [1961] 1972b). Integration of the periphery with the center shapes the specialization in the periphery and enhances performance (Schott, 1987b, 1992a).

This study focuses on a scientifically rather small country, Brazil. I shall ascertain Brazilian research performance and specialization and examine the manners and degrees of integration of Brazilian research into world science. I shall also attempt to ascertain how these developments have been shaped by the institutionalization of science in Brazil.

Brazilian society is part of the Latin American region. Brazil has rather intense links with other Latin American societies in most cultural domains, especially in religion and life style. In the economic and political spheres, Brazil participates in the regional life of Latin America and is dependent on trade and political links with other continents, mainly North America and Europe. Scientific ties are partly embedded in political-economic and other links (Schott, 1988). But insofar as scientists are attracted to loci of creative work, their scientific ties may also transcend political and economic constraints, so also for this reason we would expect Brazilian scientists to pursue ties with colleagues in the North American and Western European centers of world science. In short, we would expect Brazilian research to be attached to and variously integrated with science done in elsewhere in Latin America, in North America, and in Western Europe.

Historical and comparative perspectives: changes and contrasts

My purpose is to ascertain contemporary science in Brazil. But contemporary science can be understood better when contrasted to its own past and to science elsewhere. Therefore I adopt a historical perspective and shall ascertain changes in recent decades (as many years as time series data are available, which is back only a few decades). Furthermore, I adopt a comparative perspective and shall contrast Brazil to a place that is similar in its institutionalization of science and therefore expectedly also similar in its research, namely the rest of Latin America, and I shall compare Brazil to a place that is different in its institutionalization of science and therefore expectedly also different in its research, namely Israel. These two comparisons are suitable insofar as one is highly similar to and the other is highly different from Brazil in institutionalization of science.

I shall attempt to provide an interpretation that is up to date. However, although data go up to 1992, they tap outcomes of processes that have occurred

over some years. For example, I shall use indicators derived from publications up to 1992. But, typically, publications appear a year or so after submission of a manuscript and a manuscript is the result of a project conducted in the preceding year or so which has been designed earlier on the basis of influence received even earlier. I shall use responses from interview surveys of scientists which I directed around 1991, but the questions focused on the scientists' activity in the period from 1985 to time of interview. Furthermore, changes in policy and in funding do not have instant effects but affect scientific activity, especially results of research, with a lag of some years (for example, funding reductions in the United Kingdom entailed decline in publications only about three years later; Irvine et al., 1985). I am emphasizing that the effects are lagged because the recent acknowledged crisis in Brazilian science (see, e.g. Schwartzman, 1991: chap. 10) may not yet have had its impact on the currently available outcome measures up to 1992.

My study of individual, national, and global communal formations in science takes an institutional and interactional approach — the institutional approach is reviewed in Zuckerman (1988) and the interactional approach is reviewed in Shrum & Mullins (1988). My conceptualization of nested communal formations was developed over the years mainly from the general center and periphery theory — e.g. Greenfeld & Martin (eds.), (1988), see especially the essay by Shils. Accordingly, my perspective shares much with world-polity theory (e.g. Meyer, 1987; Ramirez, 1987) and globalization theory (Robertson, 1992) and complements or supplements the more specific political-economic world-systems theory (e.g. Chase-Dunn, 1989) and organizational field perspective (e.g. Powell & DiMaggio, 1991; Shrum, 1985). The general usefulness of my nested-level approach for disentangling complex local and global dynamics has been emphasized by Knoke (1990: 201-2), and it is compared and contrasted to the organizational approach to research endeavors by Shrum & Bankston (forthcoming).

Institutionalization of science in Brazil, other Latin America, and Israel

Science has become institutionalized in Brazil, in other Latin American societies and in Israel insofar as science is legitimated, appreciated and practiced with public backing and support. Science is appreciated in these societies partly as a cultural endeavor in its own right and partly for its multiple uses, notably for nation-building and national development in higher education, industry, agriculture, health services, the military, and as a channel for social mobility. The societies differ, however, in the firmness and pervasiveness of institutionalization and in their institutional arrangements for practicing science.

In Brazil, like in other Latin American countries, an emerging local scientific community has in the course of this century created a space for natural, medical and technological science around research institutes, some of the hospitals

and some of the universities (on Brazil, see Schwartzman 1978, 1991, esp. part 2; Velho, 1990; Velho & Krige, 1984; Verhine, 1991; and also Ben-David, 1976, 1987; on other parts of Latin America, see Albornoz, 1991; Frame, 1977; Glick, forthcoming; Inter-American Development Bank, 1988; Levy, 1986; Schwartzman, 1985, 1986; Vessuri, 1986, 1990). But most of the up toward one hundred universities and university-like institutions in Brazil, like the many professional schools and other tertiary schools, have primarily emphasized teaching. In by far most of the nearly one thousand tertiary institutions in Brazil, research has not been a significant organizational purpose, and the faculty has had little training and experience in research and has not engaged in training researchers. The small space for the education of researchers implied that when the educational system expanded rapidly since the late sixties in Brazil, like in other Latin American societies, the supply of researchers was far below the number of available academic positions, which in turn entailed a perpetuation of the two-tier academic system of a small fraction of research-oriented universities and a mass of teaching-oriented universities and professional schools. The financial support for scientific research, furthermore, has been rather turbulent and the public backing of science as a value in itself and as a means for national development is not widely rooted. The institutionalization of science is therefore rather precarious in Brazil and elsewhere in Latin America.

Earlier studies comparing scientific research in Brazil to that in other Latin American countries have found Brazil to be rather typical of Latin America with respect to social and human resources expended on scientific activity relative to population, such as stock of scientists and engineers, employment of scientists and engineers in research and experimental development, and expenditures on research and experimental development. Brazil has also been rather typical in terms of outcomes of scientific activity such as scientific publications relative to the national economic product and the influence of these publications on world science (Inter-American Development Bank, 1988). This similarity between Brazil and the rest of Latin America in both institutional conditions and some outcomes of course entails the hypothesis that the more detailed analyses undertaken here will show more similarities. Indeed, insofar as similarities are shown by all indications in the analyses, this will show the reliability of the indicators.

Israel provides a contrasting case. Israel is already known to be exceptional among the societies in the world by its high extent of scientific activity. Already in the sixties were Israeli scientific authors exceptionally numerous relative to the national economic product (Price, 1986). This high scientific activity has continued until today when Israel is the nation with the highest number of scientific articles relative to population and also relative to gross national product (Schott, 1993a). This exceptional activity is the results of several conditions.

In Israel science has been highly appreciated, both in the dominant stratum and increasingly throughout the population (Ben-David, 1962, 1964, 1986, 1991: chap. 3 with Aran and chap. 13 with Katz; Katz, 1979; Tal & Ezrahi, 1973;

Zahlan, 1970). There has been a traditionally high appreciation of learning in the Jewish culture and there has been a historically high tendency among Jews in Europe and North America to pursue higher education and scientific activities. Israeli society has an especially high demand for new and useful knowledge and for highly educated labor in several sectors, specifically health services, agriculture, industry, and the military in particular. The Israeli government and the academic institutions have had a policy of treating knowledge as a commodity that can be produced in a transnational market for research, notably by obtaining research grants and contracts from local and foreign funding sources. In short, science has in Israel been treated as a cultural endeavor as well as a social and economic investment, especially somewhat like an export industry.

Israeli science is institutionally integrated with higher education, seemingly more than anywhere else in the world. By the middle of this century the Israeli institutions of higher education were all converging on the 19th century German university model combining research and teaching and were also all modeling the American education of researchers through doctoral programs. This widely institutionalized training has produced a supply of researchers largely matching and occasionally even exceeding the demand for academic staff in the expanding Israeli system of universities (Ben-David, 1986; Schott, 1987a). By the early seventies the Israeli research enterprise had crystallized as an essentially one-tiered set of seven universities and several university-related hospitals performing by far most of the research in the natural, mathematical, medical and technological sciences. The Israeli universities have been similar insofar as they all emphasize scientific research far more than teaching or direct service to the local community, provide research facilities and have a moderate teaching load. The self-governing faculty have been appointed largely on the basis of research accomplishment and the typical qualification for entry into an academic career has been a doctoral education and postdoctoral research training, frequently abroad, and some research experience. Likewise, advancement up through the several levels in the professoriate has been based chiefly on the criterion of accomplishments in research. These standards have been promoted by including foreign eminent scientists in the evaluation of staff, departments and universities, and also on the editorial boards of the journals published in Israel. Moreover, the universities and their affiliated hospitals have been providing facilities for research and have been promoting ties with foreign colleagues in several ways, by annual travel funds to each scientist and regularized sabbaticals and frequently granted leaves of absence for sojourns in foreign research institutes, and also by bringing visiting scientists from abroad. Actually, the policies of the Israeli authorities in government and the academic institutions have included establishing rather comprehensive bilateral scientific cooperation agreements with foreign institutions and countries, for example the United States-Israel Binational Science Foundation. These comprehensive institutional arrangements have promoted an uncommonly strong integration of Israeli research with the centers of

world science which in turn has enhanced the research performance (Katz, 1978; Schott, 1987b).

The differences in institutionalization of science makes Israel a contrast to Brazil, a contrast that expectedly is informative insofar as it can be used to ascertain and explain developments in Brazilian research.

Concepts and their indicators based on the literature and a survey

The concepts for describing the scientific research enterprise are either attributes or relations. Performance is an attribute, a characteristic of a scientist or, in the aggregate, of a national scientific community. Specialization is also an attribute, here a characteristic of a national scientific community. The other concepts are kinds of role-relations between scientists or, in the aggregate, between their national scientific communities (Burt & Schott, 1989). I shall consider six analytically distinct kinds of role-relations — namely deference, travels, influence, collaboration, emulation, and concern for recognition. I shall briefly consider each concept and how the concept can be measured by one or two indicators.

Performance in scientific research refers to the creation of new public scientific knowledge. Performance in a country can be indicated by the articles in the world's major journals in science which are written by authors in the country. Another indicator is the extent to which the articles written in the country are subsequently cited in the literature. Two other indicators are the extents to which scientists in the country are named as principal contributors or as influencers on researchers surveyed in other parts of the world. These four measures are indicators of scientific performance.

Specialization refers to the substantive foci of scientific attention, the cultivation of some rather than other fields of research. Specialization in a country can be indicated by the concentration of publishing in some disciplines and sub-disciplines.

Deference of researchers refers to their appreciation of others' performance. Researchers' deference toward performance can be indicated by asking them to name principal contributors to the field.

Travels by researchers can be indicated by asking them to report their visits to other institutions and their participation in meetings abroad.

Influence upon research refers to the transfer of intellectual material and its impact on research. Influence upon researchers can be indicated by asking them who influenced their research. Another indicator of influence upon researchers can be based on their bibliographic citations to earlier publications.

Collaboration refers to joint research. Collaboration between researchers can be indicated by asking researchers about their work jointly with others. Another indicator of collaboration is jointly authored publications.

Emulation refers to competition among researchers to excel in the performance of the scientific role. A researcher's emulation can be indicated by asking about felt competition with others to be first or best in research.

Recognition refers to the validation and acknowledgment of contributions to public knowledge, and as a social reward for role performance such recognition is often of great concern to a researcher. A scientist's desire for recognition from others can be indicated by asking about caring about others recognizing the research.

These indicators are based on data from two sources: the literature of world science and surveys of scientists in Brazil and other countries. Some of the above concepts have several indicators, based on different approaches. This enables methodological triangulation by which the imperfection of each approach is countered by using several approaches. Influence, for example, can be indicated both by survey data and by literature data. Questionnaire responses to a question asking about influence are not perfect, e.g. because the sample is not perfectly representative or because the respondent does not recall influences. Also citations in articles are far from perfect, e.g. because not all influence is reflected in citations and because not all citations reflect influence. But if surveys and citations show similar distributions then we consider the indicators rather reliable.

The literature-based indicators for this study are derived from the *Science citation index* which largely covers the world's important journals in the natural, medical and technological sciences, including journals published in the poorer parts of the world (Frame, 1985; Garfield, 1979, 1983a, 1983b; Stevens, 1990). The main criterion for including a journal is its quality or impact, so the volume of indexed articles written by authors in a country is a reasonably good indicator of research performance in the country. Since 1973, the number of indexed articles has exceeded 260,000 annually. Annually, more than 4,400 of the articles were coauthored between people at different institutions. And the articles indexed in 1980-82 contained more than 1,835,000 citations referring to indexed articles published in 1978-80. The citations and coauthorships are indicators of influence and collaboration occurring in collegial ties. These indicators derived from the scientific literature are far from perfect, especially when the focus is on the areas of the world where there may be considerable research for local dissemination but few journals are published with significant impact on world science (Eisemon & Davis, 1989; Frame, 1985; Moed, 1989; Morita-Lou, 1985). This is one reason for supplementing the literature-based indicators with survey data. In fact, the survey yields indications similar to the indications derived from the literature and thereby validate the indicators based on the literature.

The other indicators are derived from a survey of collegial ties among scientists in Brazil, elsewhere in Latin America, and in Israel, using a questionnaire administered during 1990/91. Focusing on collegial networks, the unit of analysis will not be a respondent but a relationship or a dyad of researchers within a

country or in different countries. More precisely, the unit of analysis will be variously a travel (a visit to another institution or a trip to a conference), an expression of deference, a named influencer, a collaborator, a competitor, or another specific kind of role-relation. Brazilian, other Latin American, and Israeli participation in collegial networks will in the analyses be indicated by their reported 709 travels, 499 expressions of deference, and 1,228 influencers, and so forth, as listed in the tables. These relations were reported by 167 scientists, namely 64 in Brazil, 87 in other parts of Latin America (47 in Chile and 40 in Uruguay), and 16 in Israel.

Scientists were selected for the survey as follows. In each country I selected a geographically circumscribed site for survey. In Brazil, the site was a large city some distance from São Paulo with a large university with considerable research in the natural, medical and technological sciences. In the other part of Latin America, the sites were the capitals in Chile and Uruguay. In Israel the site was a city with a comprehensive university. These sites were selected because of availability of contacts and local interviewers. In each site the respondents were sampled mainly from a list, namely the list of authors of articles covered by the *Science citation index* which has a listing of authors in each city in the geographically arranged author index. The most recent list provided a sample of authors which was classified into disciplines according to the classification of journals they published in. This provided a classification of the sampled scientists into the disaggregate of science as eight disciplines: clinical medicine, biomedicine, biology, chemistry, physics, earth and space science, technology and engineering science, and mathematics. Each discipline is so broadly defined that the eight disciplines comprise all sciences. In each site the respondents were thus randomly sampled. However, this does not assure representativeness.

The restrictive selection of sites, one or two cities in each place, implies that the ties of the selected respondents are not assured to be representative of the ties of all scientists in Brazil, the other part of Latin America, and Israel. Representativeness can be gauged by methodological triangulation. It turned out, as will be shown in the tables, that in each place the respondents' reported collaborations and received influences are similar to the collaborations and influences indicated by the coauthorships and the citations in the articles by authors in the place. Therefore we can be reasonably confident that the ties reported by the respondents are rather representative of the ties of all the scientists.

The participation rate in the survey in each site exceeded 90 per cent of the contacted scientists (except that I do not know the participation rate in Israel) and the response rate on any single item in the questionnaire was also above 90 per cent.

A questionnaire was used for tapping ties of the respondents. The questionnaire briefly asked for attributes of the respondent such as education, career, research orientation (pure *versus* applied research), and research mode (experimental *versus* theoretical). Travels were tapped by two questions, *Which institu-*

tions have you visited in the last 12 months? and To which conferences abroad have you gone in the years from 1985 to present? The respondent's deference was tapped by asking about contributors, *Who are the people in the world who have performed the best scientific research in your field since 1985?* noting also the place of each named contributor.

The main part of the questionnaire tapped the collegial circle around the respondent. The interpersonal circle around a respondent can be tapped by first identifying the significant others and then asking about their attributes and their relations, a procedure that has recently gained codification by adoption in the General Social Survey in the United States (Burt, 1984). In my survey, each scientist listed significant colleagues in response to the question, *Who are the people whose specific ideas have influenced your research since about 1985?*

The tie to each named colleague was tapped by the following questions:

Through which media did their ideas influence your research?

To what extent has each person influenced your choice of problems for research?

To what extent has each person influenced your research through your reading of the person's publications?

To what extent has each person influenced your research through personal communication?

To what extent has the person been a collaborator on your research?

To what extent do you feel that you and the person are competing with one another to be first or best in research?

To what extent do you care about each person's recognition of your research?

The attribute of a named colleague which is crucial for this study is of course the colleague's location, *Where in the world is each person?*

This questionnaire provides rather detailed information on collegial networks (for validation, see Schott, 1992b).

The surveyed scientists were mostly working in academic settings, in universities or in university-affiliated hospitals. Typically they had a doctoral level education and were performing research for publication in the literature gaining international circulation. In each place roughly half reported to be doing mainly pure research and roughly half reported to be doing mainly applied research. In each place, several were doing primarily theoretical work and several were doing primarily experimental work. The age composition was also similar across the places, most had obtained their highest degree in the seventies or first half of the eighties, a few were further in their careers and a few had less experience. The groups of respondents were thus rather similar in these personal background characteristics. They differed, however, in their participation in the international collegial networks, as will be shown in the later analyses.

Performance and specialization in research

How much of the world's scientific research has been performed in Brazil and how does this compare to the size of the country in terms of population and economy? How much of the world's research in each discipline has been performed in Brazil? What have been the directions of specialization in Brazilian research? How have the performance and the specialization changed during recent decades?

Performance in Brazil and in every other place is here indicated by its scientists' share of scientific articles, the extent to which their articles are cited in other articles, other researchers' mentions of them as principal contributors, and mentions of them as influencers upon research elsewhere in the world. These four indicators of scientific performance are juxtaposed to two important conditions of science (Teitel, 1987), namely the share of Brazil in the world's population and Gross National Product, as listed in table 1.

Table 1 shows that Brazil is a scientifically small country, performing much less than 1 per cent of the scientific research in the world, and this attracts much less than 1 per cent of the citations in subsequent literature. No Brazilian scientist was among the nearly three thousands mentioned as principal contributors or significant influentials in a survey of scientists elsewhere. Brazilian research amounted to a little less than half of the research performed in the rest of Latin America and about a third of that performed in Israel, where scientific performance was high as indicated by the rather frequent mentioning of Israelis as great contributors and influentials. In economy and population, Brazil is roughly half the size of the rest of Latin America, as in science. But Brazil is a whole order of magnitude larger than Israel in terms of the economy and even more in terms of population and yet far less research is performed in Brazil than in Israel. This shows that scientific performance in a country is not a reflection of the size of the country in terms of population or economy (there is only a very weak correlation with population and a weak correlation with the economy; see Schott, 1991b). These differences in scientific performance seem shaped by differences in institutionalization of science.

Brazil and other Latin American countries have in recent decades been investing many human and material resources in expanding their scientific activities. So the question is not only one of the width of the gap to nations with higher scientific performance, but the question is also whether the gap is narrowing. The historical perspective is adopted by examining data from different years (table 2). The available data covering different decades are unfortunately not compiled by exactly the same method, but they are from similar sources, so the different counting methods presumably do not alter the indications. The earliest data are counts of authors recorded in the *Current contents*, which is published by the Institute for Scientific Information that also publishes the *Science citation index*, which has been used to count articles from the seventies to the eighties and to estimate the volume of listings up to 1993.

Table 1
Scientific performance, juxtaposed to economy and population

Percentage distribution of articles, 1986.
Percentage distribution of citations, 1980-85.
Percentage distribution of contributors named in a survey.
Percentage distribution of influencers named in a survey.
Percentage distribution of Gross National Product, 1986.
Percentage distribution of population, 1986

	Performance in scientific research				Gross National Product %	Population %
	Articles %	Cites %	Contributors %	Influencers %		
Brazil	.3	.2	0	0	1.7	2.8
Other LA	.8	.4	.1	.3	3.0	5.3
Israel	1.0	.9	2.0	.6	.2	.1
North America	40.9	54.8	49.0	45.9	31.3	5.4
Western Europe	30.8	30.8	35.2	33.9	22.7	7.2
Rest of world	26.1	13.0	13.7	19.3	41.2	79.2

Notes: The percentages in each column sum to 100 per cent except for rounding.

Sources: Articles (298,815) are from a dataset derived from the *Science citation index* for 1986 (Institute for Scientific Information) (dataset compiled by CHI Research; Stevens, 1990).

Citations (exceeding 5 million) are derived from the *Science citation index* 1980-85 (Institute for Scientific Information) (data published by Schubert et al., 1989).

Contributors (759) and influencers (2,159) are reported in a survey of scientists in Bangladesh, Czechoslovakia, Greece, India, Indonesia, Japan and the then Soviet Union (Schott, 1992b). Their mentions of compatriots are excluded from the counts.

Gross National Product is from World Bank. *World Tables 1989-90*. Baltimore, Johns Hopkins University Press; Shoup, P. S. *The East European and Soviet data handbook*. New York, Columbia University Press, 1981; and Taylor C. L. & Jodice, D. A. *World handbook of political and social indicators*. 3rd ed.. New Haven, Yale University Press.

Population is from World Bank, *World Tables 1989-90*. Baltimore, Johns Hopkins University Press; United Nations. *Demographic yearbook 1987*. New York, United Nations, 1988.

Table 2 indicates that Brazilian scientific performance grew considerably in its share of world science from the sixties throughout the seventies and the eighties to the early nineties. Research in the rest of Latin America grew slowly from the sixties to the early eighties but leveled off around the early eighties and has been rather constant in the last decade. Israeli research grew during the early seventies and was a rather constant share of world science from the mid-seventies through the mid-eighties but its share has been declining in recent years. Constant share of a place during a growth of world science of course means a continued growth of research in the place.

Table 2
Changes in scientific performance

Authors in Brazil, in the rest of Latin America, and in Israel, as percentage of the world's authors in *Who is publishing in science*, annually, 1967 to 1973.

Articles by authors in Brazil, in the rest of Latin America, and in Israel, as percentage of world's articles in a fixed set of journals in the *Science citation index*, annually, 1973 to 1986. Listings of articles by authors in Brazil, in the rest of Latin America, and in Israel, as percentage of the world's volume of listings in the *Science citation index*, 1975 to 1993

	Brazil %	Other LA %	Israel %
Authors			
1967	.17	.38	.92
1968	.14	.50	.87
1969	.18	.35	.87
1970	.19	.45	.77
1971	.19	.43	.86
1972	.24	.46	.90
1973	.28	.60	.91
Articles			
1973	.21	.73	.96
1974	.25	.71	.97
1975	.27	.65	1.00
1976	.31	.63	1.02
1977	.31	.63	1.07
1978	.31	.64	1.03
1979	.35	.67	1.01
1980	.36	.71	1.02
1981	.38	.76	1.00
1982	.33	.81	1.08
1983	.35	.81	1.07
1984	.36	.78	1.05
1985	.35	.79	1.08
1986	.35	.82	1.02
Listings			
1975-79	.40	1.07	1.05
1980-84	.49	1.19	1.11
1985-89	.54	1.22	1.10
1990	.63	1.25	.97
1991	.69	1.25	.96
1992	.71	1.29	.93
1993 (Jan./Feb.)	.74	1.20	.96

Note: Total numbers of authors exceeded 125,000 and of indexed articles exceeded 265,000 annually.

Source: Authors are from *Who is publishing in science* (Institute for Scientific Information); the numbers of authors are listed in Price, 1986: 203-5.

Articles are from the *Science citation index* from 1973 to 1986 (Institute for Scientific Information); they are the articles in a set of journals that has been constant, namely fixed as those indexed in 1973 and articles are classified by address of author (dataset compiled by CHI Research; cfr. Stevens, 1990). Listings are from the published *Science citation index* 1975 through Feb. 1993; the percentage for a country is its percentage of the printed columns in the geographical section of the author index.

Another way to consider these shifts is in terms of rank ordering. According to the listings, Israel ranked 15th among the nations in scientific activity in 1975-79 and was in the eighties surpassed by Spain and the People's Republic of China, so that Israel moved down to 17th in science by the early nineties. Brazil ranked 26th in 1975-79, trailing Austria, Norway, Finland, Czechoslovakia, Hungary and South Africa, which it surpassed in the eighties, during which it was surpassed by the People's Republic of China, so that Brazil moved up to be the 21st among the nations in scientific activity by the early nineties.

Let me, however, reemphasize that the continued growth in Brazilian scientific activity as measured by this outcome up to 1993, does not fully capture the developments in the early nineties because of the timelag between performance of research and its resulting publication. The precarious institutionalization of science in Brazil makes science very vulnerable to political and economic crises and the current turbulence, crisis and decay in Brazil is quite likely to lead to some withdrawal of social support for science (Schwartzman, 1991: chap. 8). Following the decades of enthusiasm and growing support for science, which gave the scientists considerable self-confidence, the recent lessening of appreciation of science and a leveling of support is likely to lead, if not to contraction of the national endeavor, to a loss of sense of purpose and meaning among scientists, a situation of anomie (Ben-David, [1971] 1984: chap. 9).

National research endeavors are not evenly distributed across fields of science, but are more or less concentrated in selected fields. The selection of foci of attention in a country entails a national specialization. Diversity among countries in national specialization entails a global division of labor in research. Specialization can be revealed when controlling for the research performance of each place. I shall therefore indicate the specialization in a particular field in a country not only relative to the world effort in the field but also relative to the overall research effort of the country. Specialization in a particular field is high to the extent the measure exceeds 1 and it is low to the extent the measure is less than 1, as listed in table 3.

Table 3 shows that Brazilian research was somewhat specialized. Whereas the Brazilian cultivation of the disciplines of biomedicine and earth and space science was similar to their cultivation in the world as a whole, Brazilian research emphasized biology, physics and mathematics, with comparatively less research in clinical medicine, chemistry and technological science. This indication of specialization is similar to an indication obtained by a somewhat different classification procedure which shows a Brazilian specialization in physics and mathematics and a de-emphasis especially in chemistry but also in engineering (but did not separately classify clinical medicine, biomedicine, biology, and earth and space science; Schubert et al., 1989: 401).

Table 3
Specialization into eight disciplines and their subdisciplines, 70's and 80's

Ratio of the percentage of the articles from Brazil (from the other Latin America and from Israel) that are in the (sub) discipline to the percentage of the world's articles that are in the (sub) discipline

Disciplines and subdisciplines	Brazil		Other LA		Israel	
	1970's	1980's	1970's	1980's	1970's	1980's
Clinical medicine	.70	.58	1.39	1.13	1.02	1.15
General and internal medicine	.4	.2	3.1	3.2	1.2	1.6
Allergy	1.8	.4	.8	.8	1.0	1.0
Anesthesiology	.2	.1	.1	.2	.7	.6
Cancer	.3	.2	.6	.6	1.0	1.1
Cardiovascular system	.4	.6	.6	.6	1.0	1.3
Dentistry	2.2	1.1	.8	.5	1.8	1.7
Dermatology and venereal diseases	.4	.6	.7	.4	1.1	1.0
Endocrinology	.6	.6	2.3	1.5	1.1	.9
Fertility	1.6	1.4	5.2	2.2	2.3	2.4
Gastroenterology	.8	.4	1.0	.4	.8	.9
Geriatrics	.1	.0	.2	.1	1.7	.9
Hematology	.2	.4	.7	.6	2.0	1.8
Immunology	.6	.7	.6	.6	1.5	1.2
Obstetrics & gynecology	.6	.3	1.6	.6	1.9	2.4
Neurology & neurosurgery	.6	.4	1.1	.9	1.0	1.1
Ophthalmology	.2	.3	.6	.4	1.6	1.3
Orthopedics	.2	.5	.4	.4	1.1	1.9
Arthritis & rheumatology	.4	.4	1.2	.8	.5	.8
Otorhinolaryngology	.2	.5	.3	.2	.9	2.1
Pathology	1.2	.9	2.2	.7	.8	.6
Pediatrics	.2	.3	.7	.6	1.2	2.0
Pharmacology	1.8	1.1	1.0	1.2	.7	.6
Pharmacy	.3	.1	.3	.1	.2	.3
Psychiatry	.2	.1	.4	.2	1.0	.9
Radiology & nuclear medicine	.3	.4	.4	.2	.5	.5
Respiratory system	.1	.5	.9	.7	.8	1.2
Surgery	.7	.6	.5	.3	.8	.9
Tropical medicine	9.2	10.8	6.6	6.5	.6	.9
Urology	.5	1.0	.3	.2	.7	1.1
Nephrology	2.8	.9	1.1	.4	1.8	2.1
Veterinary medicine	.5	.5	.6	.7	.6	.3
Addictive diseases	.7	.8	.6	1.0	.6	2.2
Hygiene & public health	2.1	.9	3.1	.5	.6	.6
Miscellaneous clinical medicine	.0	.1	.2	.3	1.4	1.7

(cont.)

(cont.)

Disciplines and subdisciplines	Brazil		Other LA		Israel	
	1970's	1980's	1970's	1980's	1970's	1980's
Biomedicine	1.33	1.03	1.28	.98	1.13	.98
Physiology	1.1	.7	3.5	1.7	.5	.4
Anatomy & morphology	4.5	2.4	1.7	1.6	1.0	.9
Embryology	1.1	.6	1.0	.7	.7	.8
Genetics & heredity	2.3	1.6	1.1	1.3	1.4	1.1
Nutrition & dietetics	1.2	1.4	2.3	2.1	1.0	.8
Biochemistry & molecular biology	.8	.6	1.0	.9	1.6	1.2
Biophysics	.6	.6	.6	.4	.6	.9
Cell biology, cytology & histology	1.9	1.9	1.1	.9	1.0	.9
Microbiology	.6	.7	.6	.8	1.1	1.0
Virology	.2	.2	.5	.7	1.5	1.2
Parasitology	6.0	5.9	2.7	2.1	.8	1.2
Biomedical engineering	1.7	1.0	.4	.6	1.1	1.6
Microscopy	1.4	.4	.8	.4	.2	.3
Miscellaneous biomedicine	.8	.6	.5	.4	.7	.6
General biomedical research	1.5	1.1	1.4	.8	.8	.8
Biology	1.39	1.60	1.39	1.52	1.15	1.12
General biology	2.9	2.4	.6	.5	.4	.6
General zoology	.4	.8	.7	.5	1.5	1.3
Entomology	1.4	1.8	1.2	1.4	.9	.8
Miscellaneous zoology	1.9	3.1	1.2	2.2	1.0	1.1
Marine biology & hydrobiology	.5	1.1	.8	.8	.5	.6
Botany	2.0	2.1	1.5	2.1	2.0	1.7
Ecology	.3	.2	1.0	1.5	.8	.6
Agriculture & food science	1.3	1.3	2.1	1.6	.9	.9
Dairy & animal science	.1	.4	.3	.4	1.1	1.2
Miscellaneous biology	.5	1.1	1.6	1.5	.8	.8
Chemistry	.72	.74	.61	.84	.71	.62
Analytical chemistry	1.2	1.0	.5	.5	.4	.5
Organic chemistry	.7	.6	.6	.9	1.2	.8
Inorganic & nuclear chemistry	1.4	1.0	.5	.7	.5	.3
Applied chemistry	.2	.4	.3	.5	.3	.5
General chemistry	.7	.6	.7	.8	.5	.4
Polymers	.2	.4	.4	.7	.8	.6
Physical chemistry	.7	1.1	.8	1.2	.9	.9
Physics	1.60	1.82	.61	.91	1.11	1.15
Chemical physics	1.1	1.0	.7	.9	2.1	1.6

(cont.)

(cont.)

Disciplines and subdisciplines	Brazil		Other LA		Israel	
	1970's	1980's	1970's	1980's	1970's	1980's
Solid state physics	3.2	4.0	.6	1.2	1.4	1.0
Fluids & plasmas	.4	.7	.2	.6	1.3	1.0
Applied physics	.8	.9	.3	.5	.8	1.0
Acoustics	.1	.2	.7	.7	.8	.7
Optics	.6	.8	.7	1.1	1.0	1.6
General physics	1.7	1.8	.6	.9	.7	.8
Nuclear & particle physics	2.2	2.9	1.1	1.4	1.6	1.2
Miscellaneous physics	3.0	3.0	2.1	3.2	1.1	1.1
Earth and space science	1.08	1.24	1.12	1.13	.85	.76
Astronomy & astrophysics	1.3	1.5	2.2	2.3	.8	.5
Meteorology & atmospheric science	.2	1.1	.2	.2	.7	.7
Geology	.8	.7	.8	.4	1.0	.8
Earth & planetary science	1.3	1.5	.7	.6	1.0	1.0
Geography	.0	.0	.0	.0	.0	.7
Oceanography & limnology	.4	.4	.6	.9	.4	.5
Technological science	.44	.63	.33	.48	.83	.95
Chemical engineering	.3	.3	.6	1.1	.8	.8
Mechanical engineering	.3	.3	.2	.4	1.0	1.4
Civil engineering	.4	.5	.7	.5	2.0	1.9
Electrical engineering & electronics	.7	1.0	.2	.3	.7	.8
Miscellaneous engineering & technology	.0	.0	.0	.0	.6	.0
Industrial engineering	.0	—	.7	—	1.1	—
General engineering	.1	.1	.1	.1	1.6	1.7
Metals & metallurgy	.5	.6	.4	.7	.3	.5
Materials science	.3	.6	.2	.4	.5	.6
Nuclear technology	.6	.5	.6	.6	.5	.9
Aerospace technology	.4	.3	.0	.1	1.2	1.4
Computers	.4	.9	.2	.5	1.3	1.4
Library & information science	.3	.9	.6	.2	.2	.8
Operations research & management science	.8	.6	.3	.6	1.9	1.9
Mathematics	1.49	1.58	.49	.71	1.56	1.61
Probability & statistics	.7	.9	.7	.7	1.1	1.5
Applied mathematics	.9	1.0	.4	.7	1.5	1.6
General mathematics	1.7	1.8	.5	.7	1.6	1.4
Miscellaneous mathematics	2.7	2.5	.4	.9	2.5	3.7

Notes: The 1970's denote 1973-79 and the 1980's denote 1980-86. Industrial engineering was not reported as a subdiscipline in the 1980's.

Source: *Science citation index* from 1973 to 1986 (Institute for Scientific Informations); (dataset compiled by CHI Research; Stevens, 1990).

The discipline with most rapid growth from the seventies to the eighties was technological science. The increasing specialization in the discipline of technological science was largely concentrated in its subdisciplines of computers, information science and electrical engineering and electronics. These fields are known to have been expanding in Brazil, as a result of deliberate research policies (Schwartzman, 1991: 232-6). Although these are fields of increasing specialization, they have not become the fields of major concentrations. Specialization shows concentrations mostly in tropical medicine and in parasitology; again, relative to the world distribution across fields (also this subfield specialization is consistent with that obtained by another procedure; Schubert, 1989: 448). Conversely, Brazilian research has de-emphasized the fields of geriatrics and acoustics.

By comparison, specialization has been somewhat different in the rest of Latin America, where there has been more emphasis on the disciplines of clinical medicine and less emphasis on physics and mathematics. But, like Brazil, other parts of Latin America have concentrated on tropical medicine and to some degree also on parasitology. Israeli research is less specialized into particular disciplines except mathematics which is known to be exceptionally strong in Israel (Schott, 1987b). But there are subdisciplines with particular concentrations in Israel, notably fertility. These indications of Israeli specialization is similar to that obtained by a somewhat different procedure (Schubert et al., 1989: 416 and 458).

These specializations can be partly explained as resulting from national needs and interests. Brazil and other Latin American countries have a considerable need for knowledge in tropical medicine and parasitology, whereas Israel has an interest in enhancing the fertility of the Jewish population (and in reducing the high birthrate of the Arab population). But the scientists' research is also shaped by their attention to science done elsewhere.

Deference to world science

Scientists continually evaluate work that they are aware of. They assess not only the truthfulness but also the worth of new knowledge. The appreciated contributions may become exemplars influencing their own research. Their deference toward contributions provides a mental map for orientation in the world of science. To indicate Brazilian and other scientists' deference, the respondents in the survey were asked to name those who had made the major contributions in their field in recent years and to report the location of each named contributor (table 4)

Table 4 shows that Brazilian scientists have deferred most to science in North America, second most to science in Western Europe and third most to science done in Brazil. Likewise, scientists in the rest of Latin America and in Israel also have deferred most to science in North America, second most to sci-

ence in Western Europe and third most to local science. Deference is thus toward the easily observed and intimately understood local work and toward work in the world centers of science. Despite Israel's spatial proximity to Europe, the Israeli scientists defer less to European science and more to North American science than the Brazilian and other Latin American scientists do. This can be explained by the embeddedness of collegial ties, including deference, in political and economic links which are especially strong between Israel and the United States.

Table 4
Deference to contributors to science

Percentage distribution across places of people named as outstanding by respondents in Brazil, in other Latin America and in Israel

Country of contributors	Country of respondents		
	Brazil %	Other LA %	Israel %
Brazil	18	2	0
Other LA	1	6	0
Israel	1	.4	19
North America	41	47	60
Western Europe	34	36	15
Rest of world	6	9	6
N contributors	170	282	47

Note: The percentages in each column sum to 100 per cent except for rounding.
Source: Survey of scientists in Brazil, other Latin America and Israel.

The deference toward science in various places makes for attraction toward those places and we should expect scientists to travel mainly to those places.

Travels

To what degree do scientists in Brazil travel to interact with colleagues and what are the destinations of their travels? Scientists in Brazil and the other countries were asked to report their visits to other institutions in the latest 12 months until the time of interview and to report their participation in meetings abroad from 1985 until the interview (table 5).

Table 5
Travels to other institutions and to meetings abroad

Percentage distribution of respondents' visits to other institutions; and percentage distribution of participation in meetings abroad

	Brazil %		Other LA %		Israel %	
	Visits	Meetings	Visits	Meetings	Visits	Meetings
Brazil	68	n.a.	8	18	0	0
Other LA	1	9	48	38	0	0
Israel	0	0	0	.4	31	n.a.
North America	11	31	17	16	54	56
Western Europe	10	49	26	27	15	34
Rest of world	9	12	1	1	0	10
Mean visits or meetings for a respondent	1.5	1.9	1.8	3.1	1.7	4.9

Note: The percentages in each column sum to 100 per cent except for rounding; n.a. = not available.

Source: Survey of scientists in Brazil, other Latin America and Israel.

Table 5 shows that Brazilian scientists on average made 1.5 visits to another institution in the latest year and participated in 1.9 meetings abroad in the latest six or so years. This traveling frequency is somewhat less than that of scientists in the other surveyed Latin American countries (which are much smaller than Brazil and thereby encourage travel) and much less than that of Israeli scientists whose geographical location provides little opportunity for travel. This major difference in travel has rather little to do with geographically shaped opportunity, but can be explained as a consequence of different institutional arrangements, notably the Israeli scientists' annual funds for travel as mentioned in the section on Institutionalization of science.

The Brazilian scientists' visits to other institutions were mainly within Brazil. Their travels abroad were primarily to Western Europe and secondarily to North America. But travels were also frequent between Brazil and other Latin American countries, in both directions. Table 5 also shows that scientists in other Latin American countries also traveled more to Western Europe than to North America, while Israeli scientists traveled far more frequently to North America than to nearby Western Europe. These destinations of traveling reflect their deference orientations.

The scientists' travels and deference should expectedly be reflected in the intellectual influence upon their research.

Influences from and upon world science

To what extent has research in Brazil been influenced by results from within Brazil and from other places? And, reciprocally, to what extent has research in each place been influenced by the results of Brazilian research? Into which environment has Brazilian research been most cohesively integrated in terms of influence? How have influences from and upon Brazilian scientists changed in recent decades? Through which channels have Brazilian scientists been influenced? What are the origins of influence through publications and through personal communication? What are the sources of influence on selection of problems for research by Brazilian scientists? These questions will be answered here, comparing Brazilian influences with influences involving scientists in the rest of Latin America and in Israel.

Influences upon scientists in each place are indicated by the percentage distribution of the citations in their articles, as listed in a column in table 6.

Table 6
Influence among national scientific communities, 1980

Percentage distribution of citations in articles by authors in each place (column) across places of cited author (rows)

Influencing (cited) scientists	Influenced (citing) scientists					
	Brazil	Other LA	Israel	North America	Western Europe	Rest of world
Brazil	23.2	.8	.1	.1	.1	.1
Other LA	1.4	20.2	.3	.3	.3	.2
Israel	.7	.9	24.1	.8	.8	.8
North America	41.3	47.9	48.4	75.7	39.0	35.5
Western Europe	24.0	22.7	21.5	18.0	52.7	21.3
Rest of world	9.4	7.4	5.6	5.3	7.1	42.1
N citations	3,960	9,449	18,041	914,857	621,210	267,590

Note: The percentages in each column sum to 100 per cent except for rounding.

Source: *Science citation index* (Institute for Scientific Information); citations in articles 1980-82 referring to articles 1978-80.

The first column in table 6 shows that Brazilian research was influenced mostly by results from North America and then by results from Western Europe and from within Brazil. Likewise, comparing to the second and third columns, scientists in the rest of Latin America and in Israel were also mainly influenced

by results from North America and then from Western Europe and from within their place. These origins of influence are highly similar across the three compared places. The origins of influence upon the scientists follow the patterns of their deference more than the patterns of their travels. Notably, although Brazilian and other Latin American scientists have traveled much more to Western Europe than to North America, they have deferred much more to North American science and have been much more influenced by science in North America than in Western Europe.

The first row in table 6 shows that Brazilian scientific results exerted some influence on research in the rest of Latin America, but very little on research in other continents. By comparison, the second and third rows show a little more influence from other Latin American science and much more influence from Israeli science upon research in North America, Western Europe and elsewhere.

Table 6 shows that influence has been rather strong between Brazil and the rest of Latin America, in both directions, relative to their small influence on research elsewhere. This suggests some regional integration in influence. Regional integration can be indicated as the occurring influence (in table 6) relative to the influence that we should expect if influence were not embedded in particular links between countries but influencees were independent of influencers. If influence were not selective, influence would just be proportional to the influencer's tendency to exert influence and also to the influencee's tendency to receive influence. This conception of independent influence can be formalized — such formalization is considered in Schott (1986), and used in studies of scientific influence in Schott (1987a, 1988, 1992a).

The conception of behavioral independence between influencers and influencees can be formalized by the model of statistical independence in a two-way table and involves computing expected values. The expected values are like those for the usual chi-square test of independence in a two-way frequency table except that we have no diagonal in the table of citations from each scientific community to the other communities. Under the model of independence, the expected number of citations from an influenced community r to an influencing community c is the product of two numbers $P_r Q_c$ where P_r is the tendency of r to cite others and Q_c is the tendency of c to be cited by others. The expected number can be computed from the observed frequencies of citations from each community to the other communities. The diagonal-less matrix of expected numbers has the same row-sums and column-sums as the diagonal-less matrix of observed citations — modeling of a diagonal-less table with formulas for use in computing expected numbers is in Haberman (1979: chap. 7) and is implemented in publicly available software, Eliason (1990: 16-8).

The ratio of the observed citations to the expected number of citations is a measure of integration in the web of influence. The measures of integration are

listed in table 7. Integration has been weak to the extent the measure is less than 1 and integration has been strong to the extent the measure exceeds 1.

Table 7
Integrations in influence among national scientific communities

Influencing (cited) scientists	Influenced (citing) scientists					
	Brazil	Other LA	Israel	North America	Western Europe	Rest of World
Brazil		6.8	.8	1.0	.9	1.0
Other LA	4.4		.9	1.1	.9	.9
Israel	.7	.9		1.1	.9	1.0
North America	1.0	1.1	1.1		1.0	1.0
Western Europe	1.0	.9	.9	1.0		1.0
Rest of world	1.2	.9	.7	1.0	1.0	

Note: Influence within each place is here ignored.

Source: Same as for table 6.

Table 7 shows in the first row that Brazilian research has been highly integrated with science in the rest of Latin America, and influence has been more than six times higher than expected. Reciprocally, as shown in the first column, other Latin American research has also been highly integrated with Brazilian science, and influence has been more than four times higher than expected. Integration has been stronger between Brazil and the rest of Latin America, in both directions of influence, than between any other listed places. Such regional integration also exists among, for example, the Scandinavian national scientific communities (Schott, 1992a). Contrasting the regional integration in influence, integration has been as expected between Brazil and the other major places such as North America and Western Europe, but comparatively weak between Brazil and Israel that has been integrated with North American science. The Latin American regional integration in science can be explained by the embeddedness of scientific ties in integrative links among Latin American countries in other spheres of life such as education, religion, language, economy and politics. The scientific integration between Israel and North America can be explained by its embeddedness in the strong political, economic and educational links between Israel and the United States. Collegial ties between scientists in different countries, more generally, tend to be embedded in other links between their societies, notably in education, language, politics and economy (Schott, 1988).

Influence can be indicated not only by citations but also by a survey asking scientists to report influence on their research (as discussed in the earlier section on Concepts and their indicators). Scientists in Brazil, in the rest of Latin Amer-

ican, and in Israel named people who had influenced their research. Sources of influence are indicated by the distribution of these named influencers across their locations (table 8).

Table 8

Influence upon scientists from local and distant colleagues, circa 1990

Percentage distribution of influencers named by respondents in Brazil, in other Latin America and in Israel

	Brazil %	Other LA %	Israel %
Brazil	43	4	0
Other LA	1	35	0
Israel	1	1	26
North America	25	32	55
Western Europe	25	25	13
Rest of world	6	4	7
N influencers	408	710	110

Note: The percentages in each column sum to 100 per cent except for rounding.
Source: Survey of scientists in Brazil, other Latin America and Israel.

Table 8 shows, like the citations in table 6, that influences upon scientists in Brazil, other Latin America, and Israel originate primarily from North America and secondarily from Western Europe, with considerable influence from local colleagues. These survey responses also indicate, like the citations, that there is a small but notable regional integration in influence among scientists in different parts of Latin America.

Influence seems to have changed from 1980 to 1990 as can be seen by juxtaposing tables 6 and 8. Around 1980 North American influence upon research in Latin America was roughly twice as strong as the influence from Western Europe (table 6) but by 1990 North American influence seemed only slightly stronger than influence from Western Europe upon research in Latin America (table 8). Opposite changes seem to have occurred in the case of influence upon research in Israel, namely as follows. Around 1980 North American influence was roughly twice that from Western Europe, but by 1990 North American influence was roughly four times the influence from Western Europe upon research in Israel. These changes in scientific influence may be explained as consequences of changes in the political-economic links between the places. During the eighties, Latin American political-economic links seem to have grown more with Western Europe than with North America. Conversely, West European political-economic links with Israel have cooled during the eighties. Explaining the main dif-

ferences between tables 6 and 8 as changes in influence resulting from changing geopolitical-economic links seems more plausible than attempting to attribute the differences between the tables to differences in the data sources (indexed journals for one table and sampled scientists for the other table) or in the indicators (citations in one table and a questionnaire item in the other table).

Table 9

Media channeling influence upon scientists from colleagues

Percent of the colleagues in each location who influenced through each medium

	Publications	Pre-prints	Lectures	Discussion	Telephone	Fax	Elec. mail	Post mail	Rumor	Number of colleagues
Brazil										
Brazil	48	19	31	89	10	2	2	12	5	177
Other LA	75	100	50	100	0	0	0	50	0	4
Israel	100	0	0	0	0	0	0	0	50	2
North America	94	22	16	24	1	1	1	6	12	101
Western Europe	97	19	26	50	2	3	6	17	9	101
Rest of world	91	29	9	22	0	0	9	0	0	23
Other Latin America										
Brazil	50	4	31	85	4	0	0	15	0	26
Other LA	42	11	25	96	4	2	3	9	0	244
Israel	75	25	25	25	0	0	0	50	0	4
North America	92	18	31	47	8	10	8	20	2	226
Western Europe	82	13	28	61	5	17	6	36	1	180
Rest of world	90	0	17	31	0	0	3	28	0	29
Israel										
Israel	50	44	43	82	29	7	18	18	4	28
North America	52	38	18	70	25	15	28	37	2	60
Western Europe	57	71	21	79	21	0	57	43	0	14
Rest of world	100	75	38	25	13	25	38	38	38	8

Notes: Number of colleagues in a location is the number of colleagues in that location who were reported to have exerted influence through one or more media. The Israeli respondents reported no colleagues in Brazil and the rest of Latin America.

Source: Survey of scientists in Brazil, other Latin America and Israel.

Influence is channeled through a variety of media, notably publications, preprints, lectures, discussions, telephone, facsimile messages, postal mail, and perhaps also through rumor. The interviewed scientists reported which one or more media channeled influence from each named colleague (table 9).

The left-most column in the upper part of table 9 shows that Brazilian scientists were influenced by publications by about half their significant colleagues in Brazil, publications by more of their colleagues in the rest of Latin America, and publications by the vast majority of their significant colleagues elsewhere. Publications were the most frequent medium of influence from colleagues outside Latin America. But influence from colleagues in Brazil and in the rest of Latin America was more frequently channeled through face-to-face discussions. Also other interpersonal media were channels of influence more frequently from local and Latin American colleagues than from colleagues outside Latin America.

Scientists in the other part of Latin America reported influence through the various channels to be rather similar to the channels of influence upon Brazilian scientists. Face-to-face discussion was the most frequent medium of influence from Latin American colleagues and publications were the far most frequent medium of influence from colleagues outside Latin America.

Brazilian scientists, however, differed from scientists in the other part of Latin America in that they less frequently were influenced through interpersonal media such as face-to-face discussion and postal mail. This difference indicates that Brazilian scientists, compared to scientists in the rest of Latin America, were slightly less integrated into networks of colleagues in the North American and European centers.

The bottom part of table 9 shows that Israeli scientists differed considerably from scientists in Brazil and other parts of Latin America in that publications were a less significant channel of influence upon the Israelis, while the interpersonal media were a highly utilized channel of influence, not only from local colleagues but also from colleagues in North America and Europe. Through a multiplicity of interpersonal media, Israeli scientists have been intensely integrated into circles of colleagues in the world centers, evidently far more integrated than Brazilian and other Latin American scientists.

The influence is exerted through the professional mass media, i.e. publications, and through interpersonal media, i.e. direct contact between scientists. Each respondent was asked to rate the extent to which each named colleague's publications influenced the research of the respondent. The influence from each colleague's publications was rated on a scale going from 0 for *none* through 1 for *little* and 2 for *some* up to 3 for *great* influence of the publications on the respondent (the questionnaire was described in the earlier section on Concepts and their indicators). These ratings of influence of each named colleague's publications on the respondents can be used to indicate influence from the various places, namely as follows. The influence from a place is indicated by the sum of the rated influences from the colleagues in that place, as a percentage of the overall sum of

influences from all the colleagues. A colleague whose publications had no influence, i.e. was rated 0, is ignored by the computation, and a colleague weighs heavily according to the rated influence. In other words, the computation is a weighted distribution across the sources; it is the distribution of the colleagues across places where the colleagues are weighted by the rated influence of each colleague's publications. This indication of sources of influence through publications is listed in the left side of table 10.

The left-most column in table 10 shows that Brazilian scientists were influenced through publications written by colleagues mainly in Brazil, North America, and Europe, and in similar amounts from these three places. Also scientists in the rest of Latin America were influenced through publications by colleagues from Latin America, North America, and Europe, and in similar degrees from these three places. The Latin American scientists differed from the scientists in Israel who received influence from publications by colleagues in North America much more than in Europe.

Table 10
Influence upon scientists from publications and from personal contacts

Percentage distribution of named colleagues, weighted by their rated influence through their publications.
Percentage distribution of named colleagues, weighted by their rated influence through their personal communications

	Influenced from publications			Influence from contacts		
	Brazil %	Other L.A. %	Israel %	Brazil %	Other L.A. %	Israel %
Brazil	30	3	0	65	4	0
Other L.A.	1	21	0	1	45	0
Israel	1	1	24	.4	0	28
North America	28	39	51	11	23	53
Western Europe	33	31	15	22	25	17
Rest of world	8	5	11	2	2	3
N influencing through medium	324	564	96	256	501	88

Note: The percentages in each column sum to 100 per cent except for rounding.
Source: Survey of scientists in Brazil, other Latin America and Israel.

The respondent was also asked to rate extent of each named colleague's influence through personal contact, using the same scale from 0 to 3. The influence from a place through personal communication is then indicated by the sum of the rated influences from the colleagues in that place. In other words, influ-

ences from direct contacts in the various places are indicated by the distribution of the colleagues weighted by each colleague's direct influence, as listed in the right side of table 10.

The right side of table 10 shows that the personal contacts influencing Brazilian scientists were mainly with colleagues within Brazil, whereas they were less influenced through personal contacts with colleagues in other places such as North America and Europe. In this respect, the Brazilian scientists differed from scientists in the rest of Latin America, who were more influenced through personal contact with colleagues outside Latin America. But the Brazilians and other Latin Americans differed more from the scientists in Israel, who were far more influenced by personal contact with foreign colleagues, especially in North America.

Influence is an encompassing concept. Influence on research in general encompasses influence on selection of problems for research, influence on conceptual frameworks, influence on methods of investigation, and influence on yet other aspects of research. The selection of problems for research is of most interest for understanding the direction of scientific research. Brazilian agricultural researchers have earlier reported to be much influenced by regards for national usefulness in their selection of problems for research (Velho, 1990). Here, the respondent was asked to rate each named colleague's influence on selection of problems for research by the respondent, again using the scale from 0 to 3 as described earlier. The sources of influence on problem choice are then indicated by the distribution of the ratings across places (table 11).

Table 11
Influence upon scientists' problem selection

Percentage distribution of named colleagues, weighted by their rated influence on the respondents' problem selection			
	Brazil %	Other LA %	Israel %
Brazil	42	4	0
Other LA	1	34	0
Israel	1	4	24
North America	24	32	55
Western Europe	27	25	10
Rest of world	5	4	11
N influencing problem choice	382	633	99

Note: The percentages in each column sum to 100 per cent except for rounding.
Source: Survey of scientists in Brazil, other Latin America and Israel.

Table 11 shows that the main source of influence on Brazilian scientists' selection of problems was their local colleagues. Secondly, their problem choice was influenced by colleagues in North America and in Europe, with influences in similar amounts. Their sources were rather similar to the sources influencing selection of problems for research by other Latin Americans. The scientists in the rest of Latin America were influenced mainly by Latin American colleagues, secondarily by colleagues in North America, and third most by colleagues in Europe. The Brazilian and other Latin American scientists differed from the Israeli scientists, who were less influenced by their local colleagues and more influenced by their foreign colleagues, especially North Americans, in their choice of problems for research.

The above analyses have disentangled sources and channels of influence on research in general and problem selection in particular. The analyses show that there has been a small but notable degree of regional integration in influence among scientists in Brazil and other parts of Latin America. But Brazilian science, like science done in other Latin America countries, has had little impact on research outside Latin America, in contrast to the notably larger impact of science done in Israel. Brazilian research, like research elsewhere in Latin America, has been influenced mainly by science done in North America and Europe. Earlier, North American influence was stronger than influence from Western Europe, but during the eighties the European influence has become equally strong. By contrast, research in Israel has continually been far most influenced by science in North America and this influence has become even stronger during the eighties. These influences have been influences on research in general and on problem selection in particular. Brazilian scientists, like scientists in the rest of Latin America and in Israel, have selected problems under the influence of local colleagues and have been even more influenced by their distant colleagues. The influences have been channeled through a variety of media. Brazilian scientists, like scientists elsewhere in Latin America, have been influenced by Latin American colleagues most frequently by face-to-face discussions and other interpersonal media, while influences from outside Latin America have been mediated mainly by these distant colleagues' publications. Contrastingly, influences upon scientists in Israel from their foreign colleagues have been channeled through a multiplicity of media, not primarily through publications but mainly through multiple interpersonal media, especially face-to-face discussions, telephone, facsimile messages, electronic mail, and postal mail. The Israeli scientists have been more intensely integrated into circles of distant colleagues, especially in North America. Israeli scientists' strong international integration is in some degree a consequence of their past high performance, but the high integration has a separate and considerably enhancing effect on performance — the enhancing effect of integration on performance was estimated in another study; Schott (1987a).

Influence is the intellectual substance of collegial ties in science. Another kind of intellectual role-relation among scientists is collaboration.

Collaboration

To what extents have Brazilian scientists been collaborating with local, Latin American and distant colleagues? Conversely, to what degrees have they been sought out for collaboration by scientists in various other places? Has there been a notable degree of regional integration among Latin American scientists in collaboration? How has Brazilian collaboration changed in recent decades, in science-as-a-whole and in each discipline? How does Brazilian collaboration compare to the collaboration of scientists in the rest of Latin America and in Israel? These questions will be answered in this section.

Scientists' collaboration will be indicated first by scientists' own reports about joint research. In the survey in Brazil and elsewhere, each respondent was asked to rate the extent of collaboration with each colleague named by the respondent (as discussed in the earlier section on Concepts and their indicators). Each colleague's collaboration was rated on the scale going from 0 for *none* through 1 for *little* and 2 for *some* and up to 3 for *much* collaboration with the respondent. The respondents' extent of collaboration with colleagues in a particular place can then be indicated by the sum of the rated collaboration with colleagues in that place, computed as a percentage of the overall sum of collaboration with all colleagues. In other words, the extent of collaboration with various places is indicated by the distribution of the colleagues across places, where each colleague is weighted by her or his rated collaboration (table 12).

Table 12
Collaboration with local and foreign colleagues

Percentage distribution of named colleagues, weighted by their rated collaboration with the respondents

	Brazil %	Other LA %	Israel %
Brazil	66	5	0
Other LA	0	47	0
Israel	0	0	26
North America	9	21	55
Western Europe	25	24	18
Rest of world	1	3	1
N collaborators	190	425	71

Note: The percentages in each column sum to 100 per cent except for rounding.
Source: Survey of scientists in Brazil, other Latin America and Israel.

Table 12 shows that Brazilian scientists have been collaborating mainly with colleagues within the country, secondarily with colleagues in Europe and thirdly with colleagues in North America. Scientists in the other part of Latin America had about half of their collaboration with Latin American colleagues, and most of the other half with colleagues in Europe and North America. Israeli scientists had only about one fourth of their collaboration with local colleagues, most of their collaboration was with colleagues in North America, and a small fraction was with colleagues in Europe. A notable difference is that the Israelis have mainly been collaborating with the center in North America, whereas the Brazilians' foreign collaboration has been mainly in Europe.

Table 13
Collaboration among national scientific communities, 70's and 80's

Percentage of the articles by authors in the scientific community (column) which have coauthors in other institutions (rows)

Coauthors	Authors											
	Brazil		Other LA		Israel		North America		Western Europe		Rest of world	
	70's	80's	70's	80's	70's	80's	70's	80's	70's	80's	70's	80's
Brazil	16.1		.8		.1		.1		.1		.02	
		19.7		1.1		.2		.1		.2		.05
Other LA	1.9		20.8		.1		.2		.1		.06	
		2.4		22.8		.1		.3		.3		.13
Israel	.3		.1		25.7		.3		.2		.03	
		.5		.2		29.9		.5		.4		.07
North America	12.8		12.8		10.3		31.0		4.2		2.4	
		13.6		14.1		17.0		36.9		6.9		3.9
Western Europe	8.5		6.1		6.0		3.3		26.1		2.7	
		12.4		9.7		10.6		5.5		35.9		4.5
Rest of world	2.0		2.1		0.8		1.5		2.1		17.1	
		3.2		3.9		1.5		2.5		3.6		22.0
N articles	6,149		14,252		20,916		814,350		628,527		500,696	
		8,452		18,523		24,534		873,649		696,177		561,055

Notes: The percentages in each column sum to less than 100 per cent insofar as many articles are not coauthored. The 70's denote 1973-79 and the 80's denote 1980-86.

Source: *Science citation index* from 1973 to 1986 (Institute for Scientific Information); dataset compiled by CHI Research; Stevens (1990).

Scientists' collaboration with others can also be indicated by the extent to which their publications are coauthored with people at other institutions, either within the country or in other countries. To detect change over time, the degrees of local and foreign collaboration are listed for both the earliest and latest periods for which data are available (table 13).

The coauthorships in table 13 are similar to scientists' reported collaborations in table 12, which show that the indicators have satisfactory reliability. The Brazilians' most extensive collaboration with colleagues at other institutions has been with colleagues at other Brazilian institutions. An earlier study observed a rather extensive in-house publication (i.e. publishing in printed materials issued by the institution of the author) and that the publications had 13 to 20 per cent of their citations to publications by scientists at other Brazilian institutions and on this basis concluded that there was very little communication between scientists at different Brazilian institutions (Velho & Krige, 1984). This percentage, however, is quite high compared to the less than 1 per cent of the world literature that is written by Brazilian scientists, so the observed percentages actually indicate a considerable communication among Brazilian institutions. That Brazilians collaborate more with colleagues at other Brazilian institutions than with peers in any other country and that this percentage is not much lower than the percentage of other Latin American's publications that are with colleagues at other Latin American institutions (a pool of publications about twice that in Brazil) or the percentage of Israeli's publications that are with peers at other Israeli institutions (a pool of publications about twice that in Brazil), as shown in table 13, also indicate considerable collegial ties among the Brazilian institutions, quite comparable to those among other Latin American institutions and among Israeli institutions.

Table 13 shows that the foreign collaboration has been concentrated in North America and Europe. The foreign collaboration from the seventies to the mid-eighties was apparently mainly with North American colleagues (table 13), but then became mainly with European colleagues (table 12). The Brazilians' switch in collaboration from North America toward Europe is consistent with the switch in Brazilians' received influence, from mainly American influence toward mainly European influence (as was discussed in the preceding section).

Table 13 shows that Brazilian scientists' collaboration has increased from the seventies to the eighties, both with colleagues at other Brazilian institutions and with colleagues in every foreign place. But their foreign collaboration has increased at a faster rate than their local collaboration. This fast increase in foreign collaboration is not unique to Brazil but obtains in every place as shown in the table. The increasing transnational collaboration is part of the globalization of science, which may be partly explained by the embeddedness of scientific ties in links among nations in spheres such as the economy and the polity which are in a process of globalization (Schott, 1991b).

Table 13 shows that Brazilian scientists have had some collaboration with colleagues in the rest of Latin America. Their Latin American collaboration has been small relative to their collaboration with colleagues in North America or Europe, but evidently large compared to, say, Israeli scientists' collaboration with colleagues in Latin America. This suggests some regional integration in collaboration within Latin America. To highlight this integration we can control for the tendency of each country's scientists to collaborate.

Integration in collaboration between places can be indicated by their actual coauthorships relative to their expected frequency if collaboration occurred independently between scientific communities, that is, in proportion to each community's tendency for outside collaboration. The expected frequency of coauthorships between two communities can be computed from the diagonal-less matrix of coauthorships, like earlier described for influence. Integration in collaboration between two places is then indicated by the ratio of the actual coauthorships to their expected frequency. The resulting measures of integration in collaboration are listed in table 14. Collaboration between two places is dense to the extent the measure exceeds 1 and collaboration is sparse to the degree the measure is less than 1.

Table 14
Integration in collaboration among national scientific communities, 70's and 80's

Coauthors	Authors											
	Brazil		Other LA		Israel		North America		Western Europe		Rest of world	
	70's	80's	70's	80's	70's	80's	70's	80's	70's	80's	70's	80's
Brazil			4.2		.7		1.3		.9		.4	
				4.5		.7		1.1		1.0		.6
Other LA	4.2				.3		1.4		.7		.5	
		4.5				.2		1.3		.8		.7
Israel	.7		.3				1.5		.9		.3	
		.7		.2				1.5		.9		.3
North America	1.3		1.4		1.5				1.0		1.0	
		1.1		1.3		1.5				1.0		1.0
Western Europe	.9		.7		.9		1.0				1.1	
		1.0		.8		.9		1.0				1.1
Rest of world	.4		.5		.3		1.0		1.1			
		.6		.7		.3		1.0		1.1		

Notes: The 70's denote 1973-79 and the 80's denote 1980-86.
Source: Same as table 13.

Table 14 shows that there has been a considerable regional integration in collaboration between Brazilians and scientists in the rest of Latin America, and collaboration has been four times more frequent than expected. The regional integration in Latin America has exceeded the integration in collaboration between Israelis and scientists in North America which has also been strong. The integration in Latin America has even increased slightly from the seventies to the eighties. In the seventies Brazilian researchers collaborated especially much with colleagues in North America, but that integration has weakened and instead Brazilians have intensified collaboration with colleagues in Western Europe and other parts of the world.

Collaboration varies from one discipline to another. Collaboration may be easier in some disciplines than in others, perhaps especially long-distance collaboration. Research in some disciplines may be so complex that it requires extensive collaboration. The extents of local and foreign collaboration in each discipline can be indicated by the frequency of coauthorships, listed in table 15.

Table 15

Collaboration with local and foreign colleagues, by discipline, 70's and 80's

The percentage of the articles involving scientists in Brazil (and in the rest of Latin America, and in Israel) which had coauthors at other institutions within the country, and the percentage which had coauthors abroad

	Local collaboration						Foreign collaboration					
	Brazil		Other LA		Israel		Brazil		Other LA		Israel	
	70's	80's	70's	80's	70's	80's	70's	80's	70's	80's	70's	80's
Science-as-a-whole	18	23	24	27	28	35	25	32	24	30	17	28
clinical medicine	27	33	34	39	55	61	19	31	17	20	10	15
biomedicine	21	29	19	26	23	30	21	33	20	28	20	33
biology	22	25	16	21	22	26	34	36	35	41	11	22
chemistry	16	21	10	13	11	16	17	19	19	23	14	27
physics	13	17	18	23	16	15	28	31	37	35	27	50
earth & space science	10	10	12	13	16	22	48	47	59	74	26	47
technological science	12	20	16	23	12	13	35	44	29	38	17	28
mathematics	4	13	8	7	5	9	43	47	42	38	38	53

Notes: The 70's denote 1973-79 and the 80's denote 1980-1986.

The number of articles involving Brazilian authors (and authors in each of the other two places) in each discipline in each period is at least 238.

Source: *Science citation index* from 1973 to 1986 (Institute for Scientific Information); dataset compiled by CHI Research.

Table 15 shows that collaboration varied considerably among the disciplines. In all three places collaboration in mathematics has been infrequent within the place but frequent with foreigners, which is undoubtedly due to the ease of long-distance collaboration in this discipline that does not depend on tinkering with apparatus for making empirical observations and experiments. The more experimental disciplines have higher degrees of local collaboration.

The increase in both local and foreign collaboration in science as a whole has occurred in some disciplines more than in others. In Brazilian earth and space science there has been no increase in local or in foreign collaboration. But there have been considerable increases in local collaboration in mathematics, technological science and biomedicine and in foreign collaboration in technological science, biomedicine, and clinical medicine. The simultaneous increases in local and foreign collaboration suggest that a discipline may be both local and cosmopolitan in its collaborative orientations.

The above analyses of collaboration have shown that Brazilian scientists have had a considerable degree of collaboration with one another and with foreign colleagues, mainly in North America earlier and increasingly in Western Europe. They have also had a notable collaboration with colleagues in other Latin American countries, so that there is some regional integration in collaboration, but the regional collaboration is infrequent compared to the extensive collaboration with colleagues in the North American and European centers.

Communal attachments: emulation and recognition

The above analyses of influence and collaboration have examined the scientists' intellectual integration into collegial networks. A scientist lives not only from intellectual material. The intellectual integration is also sustained by a social integration, by the scientist's communal attachments to her collegial circle which in turn integrates her into wider circles in the world scientific community. A scientist's social integration will here be examined in terms of her emulation with colleagues and her caring about receiving collegial recognition of her work.

Emulation refers to the desire to excel, the ambition to equal or surpass others (the word emulation also occasionally denotes imitation but that is not the meaning used here). A researcher competes with others in the performance of the scientific role, and competes with others in the creation of contributions to public knowledge, specifically for rewards for making contributions. Emulation was tapped in the survey of scientists in Brazil, in other parts of Latin America, and in Israel by asking each respondent to rate the degree of felt competition with each named colleague to be first or best in research. The respondent rated competition with each colleague on the scale from 0 for *none* up to 3 for *much* competition with the colleague. Sources of emulation are then indicated by the distribution of the colleagues, weighted by their degree of competition (table 16).

Table 16
Emulation of local and distant colleagues

Percentage distribution of named colleagues, weighted by their rated extent of competition with the respondents

	Brazil %	Other LA %	Israel %
Brazil	64	3	0
Other LA	0	35	0
Israel	2	0	25
North America	5	40	48
Western Europe	27	21	15
Rest of world	3	1	11
N emulators	75	158	53

Note: The percentages in each column sum to 100 per cent except for rounding.
Source: Survey of scientists in Brazil, other Latin America and Israel.

Emulation is seen, from table 16, to originate partly from the local environment and partly from abroad, but the scientists differ in their feelings of local *versus* foreign competition. The Brazilian scientists feel competition mainly from their local colleagues, some from their European colleagues but little from their North American colleagues. Scientists in other parts of Latin America feel less competition from their local colleagues but feel much more competition from their North American colleagues. Scientists in Israel feel even less local competition and even more competition from North American colleagues. Therefore, also in terms of emulation, Brazilian scientists seem less integrated into the world scientific community than other Latin American scientists and, especially, than scientists in Israel.

Social integration can also be ascertained in terms of caring for collegial recognition as a validation and a social reward available for the performance of the scientific role. Scientists often care about receiving recognition for their work, but they consider recognition more important from some than from others. Each respondent rated her/his caring about receiving recognition of her/his work from each named colleague, using the scale from 0 to 3. The distribution of the colleagues, weighted by the salience of their recognition, indicates the salience of various places as valued sources of recognition (table 17).

Table 17
Importance of receiving recognition from local and distant colleagues
Percentage distribution of named colleagues, weighted by their rated importance as recognizers of the respondent's work

	Brazil %	Other LA %	Israel %
Brazil	51	4	0
Other LA	1	35	0
Israel	4	1	28
North America	20	32	49
Western Europe	23	26	15
Rest of world	5	3	8
N recognizers	338	629	100

Note: The percentages in each column sum to 100 per cent except for rounding.
Source: Survey of scientists in Brazil, other Latin America and Israel.

Recognition is valued from local colleagues and from foreign colleagues. But the salience of the local environment and of foreign places as sources of recognition differ among the respondents. Brazilian scientists attach about the same importance to local and foreign sources of recognition. Scientists in other parts of Latin America attach less importance to local recognition and more importance to recognition from colleagues in North America. Israeli scientists attach even less significance to local recognition and care even more about recognition from their colleagues in North America.

In short, the scientists are not only intellectually but also socially integrated in terms of emulating and desiring recognition from local and distant colleagues. Brazilian scientists seem a little more integrated with local colleagues and a little less with distant colleagues than do scientists in other parts of Latin America and, especially, than do scientists in Israel.

Audience-orientations

The last kind of role-relation among scientists to be examined here is the orientation towards collegial audiences. A scientist makes her/his findings common property by publishing them and may often want to reach the widest possible audience, namely the global scientific community in the scientist's specialty, but a scientist also has a primary audience, the colleagues that are primarily addressed.

Scientists' addressing of audiences can be indicated by where they publish their articles. They publish some works in locally published journals and some in journals published in various other places. The distribution of articles written by authors in a scientific community across places of publication is listed in a column in table 18. As emphasized at the beginning of this essay, however, this study does not examine research for local consumption, but focuses on research contributing to world science. Specifically, for example, the distribution in the first column of table 18 largely ignores Brazilian authors' works in Brazilian journals published mainly in Portuguese and in other Latin American journals published mainly in Spanish. Rather, the first column shows the primary audiences that Brazilian authors address when they present their contributions to world science.

Table 18

Audience-seeking among national scientific communities, 1982

Percentage distribution of the articles written by authors in the scientific community (column) across places of publication (rows)

Place of publication	Author							
	Brazil	Other LA	Israel	North America	Western Europe	Rest of F. World	Second World	T. World (ex LA)
Brazil	13.5	.04	.0	.00	.00	.00	.00	.00
Other LA	.5	20.9	.0	.03	.01	.01	.00	.04
Israel	.0	.3	11.1	.04	.07	.00	.01	.06
North America	44.1	41.4	46.1	77.6	24.2	26.3	6.3	24.8
Western Europe	39.1	35.6	41.0	21.1	73.5	39.0	16.3	39.2
Rest of First World	.4	.3	.4	.4	.3	33.8	.6	.7
Second World	2.1	1.5	1.0	.8	1.8	.8	76.8	4.3
Third World (ex LA)	.5	.0	.3	.1	.1	.1	.0	31.0
N articles by authors in place	1,060	2,233	3,795	187,054	135,028	8,987	33,350	15,689

Notes: The percentages in each column sum to 100 per cent except for rounding.

Rest of First World denotes Japan, South Africa, Australia, New Zealand; the Second World denotes the then communist East Bloc of the Soviet Union and Eastern Europe; and the Third World, excluding Latin America, denotes most of Asia and Africa.

Source: *Science citation index* for 1982 (Institute for Scientific Information).

The first column of table 18 shows that Brazilian authors had their primary audiences in North America and Europe. Also authors in the rest of Latin America and in Israel addressed these primary audiences. Authors in North America and in Western Europe addressed their works primarily toward their local col-

leagues. Authors in the rest of the so-called First World addressed themselves toward local audiences and audiences in Europe and North America. Works by authors in the then communist countries, the so-called Second World, were addressed mainly to local audiences, much less often were their primary audiences in Western Europe and even far less frequently in North America. Authors in the so-called Third World (here excluding Latin America listed in other columns) addressed local audiences and audiences in Europe and North America. Nowhere outside Brazil did authors notably address colleagues in Brazil. And nowhere outside Latin America did authors notably address colleagues in Latin America. Only to a very small extent did Brazilian authors address collegial audiences in the rest of Latin America and to an even lesser extent did authors in the rest of Latin America address a Brazilian audience. The smallness of this orientation is probably due to the difference in language, Portuguese in Brazil and Spanish elsewhere in Latin America.

The phenomenon of audience-orientation can of course also be viewed from the other end of the tie, the audience. The attraction of each national scientific community as a primary audience can be indicated by the extent to which their locally published journals are outlets for works by authors around the world. This is indicated by counts of articles by various countries' authors published in journals in various countries as for table 18, but now percentaging across countries of authors, as listed in a row in table 19.

The first row in table 19 shows that Brazilian scientists have been a primary audience only for work by local authors. They have not been an audience addressed by foreign authors. The second row shows that scientists in the rest of Latin America have been an audience for work by Latin American authors and also somewhat of an audience for work by authors outside Latin America, notably work by authors in North America. Scientists in Israel have also been an audience for local work and also rather frequently a significant audience for work by foreign authors. Likewise, scientists in each part of the First World have been an attractive audience for local work and also for work by others. Scientists in the Second World were an audience mainly for local work and much less for work by authors in the First or Third Worlds. Scientists in the Third World have been an audience mainly for local work and, like Brazilian scientists, have hardly been addressed by other authors.

Audience-seeking and audience-attraction result partly from the performance of authors in the various scientific communities, partly from the volume of mainstream publications published in the various countries, the preferences of authors in certain places for publishing in certain places, and of course also the quality of the journals through which the audience-seeking is expressed.

Journals

The last aspect of the research enterprise to be examined here is the journals through which the scientists present their contributions to the common stock of

Table 19
Audience-attraction among national scientific communities, 1982
Percentage distribution of the articles published in each place (row) across countries
of the authors (columns)

Place of publication	Authors							N articles in journals in place	
	Brazil	Other LA	Israel	North America	Western Europe	R. of F. World	Second World		T. World (ex LA)
Brazil	94.1	.7	.0	2.0	2.6	.0	.7	.0	152
Other LA	.9	84.8	.0	10.5	2.4	.2	.0	1.3	551
Israel	.0	1.0	68.7	13.4	15.1	.0	.3	1.5	614
North America	.2	.5	.9	76.7	17.3	1.3	1.1	2.1	189,240
Western Europe	.3	.5	1.0	25.2	63.4	2.2	3.5	3.9	156,661
Rest of First World	.1	.1	.4	14.9	9.2	68.6	4.4	2.3	4,422
Second World	.1	.1	.1	5.0	8.0	.2	84.3	2.2	30,376
Third World (ex LA)	.1	.0	.2	2.7	2.7	.2	.3	93.8	5,180

Notes: The percentages in each row sum to 100 per cent except for rounding.
Source: Same as table 18.

knowledge. I shall examine the influence of a journal on subsequent research. Brazilian journals shall be compared to journals published in the rest of Latin America, in Israel, and to the mainstream journals in the world (whether or not to include a journal of course occasionally becomes a conflict; for a Latin American case, see Vessuri, 1987). The journals to be examined are those that have been covered by the *Journal citation reports* of the *Science citation index* during 1975-88. The Brazilian journals are:

Revista Brasileira de Medicina in internal and general medicine;

Revista Brasileira de Pesquisas Médicas e Biológicas in internal and general medicine;

Brazilian Journal of Medical and Biological Research in experimental and research medicine;

Memórias do Instituto Oswaldo Cruz in experimental and research medicine;

Revista do Instituto de Medicina Tropical de São Paulo in tropical medicine;

Arquivos da Escola de Veterinária da Universidade Federal de Minas Gerais in veterinary medicine;

Revista Brasileira de Genética in genetics and heredity;

Anais da Academia Brasileira de Ciências in multidisciplinary sciences; and

Pesquisa Agropecuária Brasileira in multidisciplinary sciences.

Their six fields are classes constructed by the source of these data which also provided the classification of the Brazilian journals except two (*Revista Brasileira de Medicina* and *Pesquisa Agropecuária Brasileira*) which we classified into one of these six fields mainly according to the provided classification of journals that they referred to.

These Brazilian journals shall be compared to the journals in their field which were also covered by the *Science citation index*. The index in the period 1975 to 1988 included 433 journals in these six fields, namely 109 journals in internal and general medicine, 55 in experimental and research medicine, 14 in tropical medicine, 93 in veterinary medicine, 74 in genetics and heredity, and 88 in multidisciplinary sciences, but not all these journals were included in a particular year.

These fields in the index also included seven journals published in the rest of Latin America, namely:

Archivos de Biología y Medicina Experimentales in internal and general medicine;

Medicina — Buenos Aires in internal and general medicine;

Revista de Investigación Clínica in internal and general medicine;

Revista Médica de Chile in internal and general medicine;

Archivos de Investigación Médica in experimental and research medicine;

Interciencia in multidisciplinary sciences; and

Acta Científica Venezolana in multidisciplinary sciences.

The six fields in the index also included four journals published in Israel, namely:

HaRefuah in internal and general medicine;

Israel Journal of Medical Sciences in internal and general medicine;

Refuah Veterinarith in veterinary sciences; and

Israel Journal of Technology in multidisciplinary sciences.

These journals will be compared to the journals published in Brazil with respect to their influence. The influence of a journal refers to the impact of its articles on further research, like the phenomenon of influence of people examined earlier in this study. Influence of an article can be indicated by its subsequent citations, citations in subsequent publications referring to the article (as influence was also operationalized for table 6). Such frequency of citations to the articles appearing in the journal have been listed in the *Journal citation reports* (Institute for Scientific Information, annually) published together with the *Science citation index*. More precisely, this measure of impact of a journal in a year is the ratio of the number of citations given in the year referring to articles that appeared in the preceding two-year period to the number of these articles in that period in the journal. The influence of a journal is hereby measured as the average impact of its articles and is thus not affected by the number of articles appearing in the journal (considerations of this impact measure are provided by Sivertsen, 1991: 64-8).

A journal may be compared each year to the other journals in its field which are reported in the *Journal citation reports* in the year. The reported journals can

be ranked according to their impact each year. The percentile rank of a particular journal denotes the percentage of the reported journals in its field that have impact at or lower than the particular journal. The annual percentile rank of each Brazilian, other Latin American and Israeli journal, within their fields, are listed in table 20. A journal is of course ranked only for those years in which its impact measure was reported in the data source.

Tabela 20
Influence of journals, by field and year, 1975-88

Percentile rank of each Brazilian, other Latin American and Israeli journal													
1975	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88
Internal and general medicine:													
<i>Revista Brasileira de Medicina</i>													
.	.	1	2	1	2	2	1	2	1	1	1	1	1
<i>Revista Brasileira de Pesquisas Médicas e Biológicas</i>													
.	.	.	4	2	8	6	7	.	.	.	.	.	.
<i>Archivos de Biología y Medicina Experimentales</i>													
.	.	.	.	.	47	65	69	50	63	60	59	59	58
<i>Medicina — Buenos Aires</i>													
43	17	57	47	49	52	53	40	40	27	35	34	42	29
<i>Revista de Investigación Clínica</i>													
14	33	21	27	31	23	38	27	13	19	13	19	3	4
<i>Revista Médica de Chile</i>													
11	20	31	26	13	20	24	17	35	20	33	21	22	12
<i>HaRefuah</i>													
.	.	3	5	.	.	.	.	.	.	.	.	.	.
<i>Israel Journal of Medical Sciences</i>													
53	57	69	63	60	67	59	53	62	45	42	40	38	41
Experimental and research medicine:													
<i>Brazilian Journal of Medical and Biological Research</i>													
.	.	.	.	.	.	.	28	47	31	25	29	28	30

(cont.)

(cont.)

	1975	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88
<i>Memórias do Instituto Oswaldo Cruz</i>	12	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Archivos de Investigación Médica</i>	8	7	17	12	6	38	10	21	5	8	2	2	2	6
Tropical medicine:														
<i>Revista do Instituto de Medicina Tropical de São Paulo</i>	.	.	.	.	.	.	.	.	.	.	16	28	21	30
Veterinary medicine:														
<i>Arquivos da Escola de Veterinária da Universidade Federal de Minas Gerais</i>	.	.	.	.	2	2	3	5	2	1	.	.	.	.
<i>Refuah Veterinarith</i>	.	.	.	32	25	.	.	.	.	.	.	.	.	.
Genetics and heredity:														
<i>Revista Brasileira de Genética</i>	.	.	.	.	.	.	.	4	4	6	7	.	1	1
Multidisciplinary sciences:														
<i>Anais da Academia Brasileira de Ciências</i>	28	5	15	51	34	29	29	41	22	49	23	17	10	12
<i>Pesquisa Agropecuária Brasileira</i>	.	.	.	.	.	.	.	.	10	3	3	5	6	5
<i>Interciencia</i>	.	.	.	29	52	52	26	20	33	45	51	60	37	29
<i>Acta Científica Venezolana</i>	33	22	50	42	42	38	20	.	.	.	.	.	.	.
<i>Israel Journal of Technology</i>	45	49	25	7	19	8	12	23	1	11	.	.	.	.

Note: Years in which influence was not reported are indicated by a dot (.).

Source: *Journal citation reports* for 1975 to 1988 (Institute for Scientific Information).

Before interpreting the rankings in table 20, I reemphasize that the journals included in the *Journal citation reports* (as in the *Science citation index*) are largely the journals that are of eminence. Therefore, the listed journals and their comparisons are largely journals with considerable influence, so the ranking is among influential journals. A journal listed with a low percentile rank is thus a journal which seemingly is influential and much more influential than most journals in the world (largely those that are not included in the data source) but is not among the few most influential journals in its field. Table 20 shows a tendency for the least influential ones to be included only occasionally, notably the two Israeli journals with titles in Hebrew for medicine and veterinary medicine (in *HaRefuah* the articles are published in Hebrew and the abstracts are also published in English).

The first row of table 20 shows that the *Revista Brasileira de Medicina* has not been one of the top journals among the covered journals in internal and general medicine which were reported in the *Journal citation reports*. Another Brazilian journal in the same field, *Revista Brasileira de Pesquisas Médicas e Biológicas*, has also not been among the top journals. The four journals published elsewhere in Latin America have ranked somewhat high while one Israeli journal ranked low and one Israeli journal ranked rather high among the covered journals in internal and general medicine.

In experimental and research medicine, the *Brazilian Journal of Medical and Biological Research* has been quite influential while another Brazilian journal, *Memórias do Instituto Oswaldo Cruz*, was less influential (and was probably found not to be so influential as to be covered since the seventies). A journal published elsewhere in Latin America has been among the rather influential journals in experimental medicine.

In tropical medicine, the Brazilian journal *Revista do Instituto de Medicina Tropical de São Paulo* has been quite influential.

In veterinary medicine, the Brazilian journal *Arquivos da Escola de Veterinária da Universidade Federal de Minas Gerais* has been one of the less influential ones and also the Israeli journal *Refuah Veterinarith* has been one of the less influential ones among the covered journals in the field.

The journal *Revista Brasileira de Genética* has been among the less influential ones in genetics and heredity.

In the multidisciplinary sciences, the *Anais da Academia Brasileira de Ciências* has been of changing influence, apparently more influential around the first half of the eighties than earlier and later. The other Brazilian journal in this field, *Pesquisa Agropecuária Brasileira*, has been among the less influential one. The two journals published elsewhere in Latin America have been somewhat more influential, while the Israeli journal has apparently become less influential over time.

To summarize these rankings among the influential journals within each field, about a handful of Brazilian journals have evidently been among the highly

influential journals in the world, and a couple of these Brazilian journals have actually been especially influential. Another handful have been somewhat influential. Apart from annual fluctuations which may be due to just an occasional influential article, the influence of each Brazilian journal has apparently been rather stable over the years, with the exception of one journal that apparently had an especially influential period. Among the other Latin American and Israeli journals in these fields, some were more and some were less influential, and most were stable but several were apparently of declining influence. Compared to the mixed stable and declining influence of journals published in the rest of Latin America and Israel, the stability of influence of the Brazilian journals appears as a slight comparative increase.

Conclusions

The above series of analyses were undertaken to answer the question of how Brazilian scientific performance, specialization and ties with local, regional and central colleagues have been shaped by the institutionalization of science in Brazil. Therefore trends in Brazilian research were ascertained and Brazil was compared to the other Latin America and to Israel which have had similar and different, respectively, institutional arrangements.

Science has become institutionalized in Brazil insofar as it has become rather appreciated and been granted considerable autonomy and some support. Scientific activities such as research and training of researchers, however, have been concentrated in a fraction of the universities in Brazil and elsewhere in Latin America, unlike in Israel where scientific research and training has been the primary purpose at all the universities.

This difference between Brazil, or Latin America more generally, and Israel in their institutional arrangements for science has enhanced scientific performance in Israel so that research performance has been higher in Israel than in Brazil and in the rest of Latin America. Israeli performance has been higher not only relative to population and the economy but also in total, despite the smallness of the country. But scientific research has expanded in Brazil, and the Brazilian rate of increase was higher than in the rest of Latin America, in Israel, and in the world as a whole. The Brazilian performance has been increasing throughout the eighties. A decline in social and human investment in scientific activity takes some years to cause a decline in the outcomes of research. The recent Brazilian crisis has not showed up as a decline in the Brazilian publications by 1993, but will probably entail a decline within a few years.

Brazilian research has been specialized insofar as certain disciplines and specialties have been foci of scientists' attention in Brazil more than elsewhere. Brazilian specialization has emphasized the disciplines of physics, biology and mathematics, it has been more typical in biomedicine and earth and space science, and has de-emphasized clinical medicine, chemistry and technological sci-

ence. Within medicine, though, tropical medicine and parasitology have been fields of strong specialization in Brazil, like in other parts of Latin America, but unlike in Israel where specialization has focused on mathematics and fertility. Brazilian growth has been highest in technological science, especially in fields of computing. These directions of Brazilian specialization seem shaped by national needs and research policies.

Brazilian scientists have been tied to colleagues who have influenced their research, and also been variously collaborators and competitors in research, and often also been significant recognizers of their work. None of these ties have been confined within Brazil but have also been rather extensive with foreign colleagues. Brazilian research has been integrated with science in the rest of Latin America insofar as regional influence and collaboration have been higher than expected. This integration in collegial ties has been promoted by their embeddedness in the strong links between Brazil and the rest of Latin America in other spheres of life. The regional integration has been notable but has been overshadowed by the attachment to the centers of science, located in North America and Western Europe. Scientists in Brazil, like elsewhere, have deferred mainly to these centers, have traveled there, been influenced by science in the centers, occasionally collaborated there and valued recognition from colleagues in the centers. The involvement of Brazilian scientists with the centers, though, has been slightly less than the involvement of other Latin American scientists and much less than the participation of Israeli scientists in the centers. The Israeli ties with the centers, especially the North American center, have been enhanced by their embeddedness in the strong political and economic links between Israel and the United States and also by institutional arrangements for science such as comprehensive scientific cooperation agreements with the centers and travel funds which are results of Israeli research policies enhancing research performance through integration with centers of science.

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